4. MAJOR ACTIVITIES

The previous section outlined the science activities pursued in the Laboratory for Atmospheres. This section presents summary paragraphs of some of our major activities in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for NOAA's remote sensing requirements. The section concludes with a listing of project scientists, and a description of interactions with other scientific groups.

4.1 Measurements

Studies of the atmosphere of Earth require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the principal instruments that were built in the Laboratory, for which a Laboratory scientist has had responsibility as Instrument Scientist, or for which Laboratory scientists are responsible for algorithm development, calibration and data analysis. The instruments are grouped according to the scientific discipline each supports. Table 4.1 also indicates each instrument's deployment—in space, on aircraft, balloons, on the ground, or in the laboratory. In most cases, details are presented in a separate Laboratory technical publication, the *Instrument Systems Report,* NASA/TP-2005-212783 which is also available on the Laboratory's home page, http://atmospheres.gsfc.nasa.gov/.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
Space	GLAS TRMM	OMI	GLAS TRMM MODIS
Aircraft/Balloon	EDOP HARLIE TWiLiTE (IIP) URAD HIWRAP (IIP)	AROTAL RASL (IIP) ACAM	CPL THOR Lidar CRS UAV CPL

Ground/ Laboratory/ Development	SRL GLOW	STROZ LITE AT Lidar Brewer UV Spectrometer KILT Pandora Spectrometers L2-SVIP GeoSpec (IIP)	MPL COVIR SMART COMMIT

ACAM	Airborne Compact Atmospheric Mapper
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ATL	Aerosol and Temperature Lidar
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Tropopause
COVIR	Compact Visible and Infrared Radiometer
CPL	Cloud Physics Lidar
CRS	Cloud Radar System
EDOP	ER-2 Doppler Radar
GeoSpec	Geostationary Spectrograph
GLAS	Geoscience Laser Altimeter System
GLOW	Goddard Lidar Observatory for Winds
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
IIP	Instrument Incubator Program
KILT	Kiritimati Island Lidar Trailer
L2-SVIP	Lagrange-2 Solar Viewing Interferometer Prototype
MODIS	Moderate Resolution Imaging Spectroradiometer
MPL	Micro-Pulse Lidar
OMI	Ozone Monitoring Instrument
RASL	Raman Airborne Spectroscopic Lidar
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SRL	Scanning Raman Lidar
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
THOR	cloud THickness from Offbeam Returns
TRMM	Tropical Rainfall Measuring Mission
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAV	Unmanned Aerial Vehicle
URAD	Unmanned Aerial Vehicle Radar
UV	Ultraviolet

4.2 Field Campaigns

Field campaigns use the resources of NASA, other agencies, and other countries to carry out scientific experiments, to validate satellite instruments, or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2, DC-8, and WB-57F serve as platforms from which remote sensing and *in situ* observations are made. Ground-based systems are also used for soundings, remote sensing, and other radiometric measurements. In 2006, Laboratory personnel supported eleven such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

4.2.1 Aura Validation Experiment (AVE)

AVE is a measurement campaign designed to acquire correlative data needed for the validation of the Aura satellite instruments. Aura was launched in July 2004 with four instruments: the Ozone Monitoring Instrument (OMI), Tropospheric Emission Spectrometer (TES), Microwave Limb Sounder (MLS), and the High Resolution Dynamics Limb Sounder (HIRDLS). Aura has three science objectives: 1) analyze the recovery of the ozone layer, 2) assess air quality problems, and 3) determine how the Earth's climate is changing.

During 2004 and 2005 three AVE missions were flown using the NASA WB-57F and NASA DC-8 aircraft. These missions have continued in 2006 with the Costa Rica Aura Validation Experiment (CR-AVE).

4.2.2 Costa Rica Aura Validation Experiment (CR-AVE)

The Costa Rica Aura Validation Experiment (CR-AVE), running from January 15 to February 14, 2006 was the fourth in a series of similar NASA-led science missions to acquire high quality measurements of the tropical atmosphere to validate data from NASA's Aura satellite. Such experiments allow scientists to directly measure the transport of gases and aerosols in the lower atmosphere (or troposphere) and their exchange with the lower stratosphere. This data is then compared with that from Aura to enable improved modeling of global-scale air quality and climate change predictions.

The fourth AVE campaign was staged in Costa Rica in January and February 2006. The NASA WB-57F carried a total of 29 instruments in two separate payloads. The first payload was composed of both *in situ* and remote sensing instruments. A total of six flights were conducted that were precisely timed to coincide with the Aura overpass. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

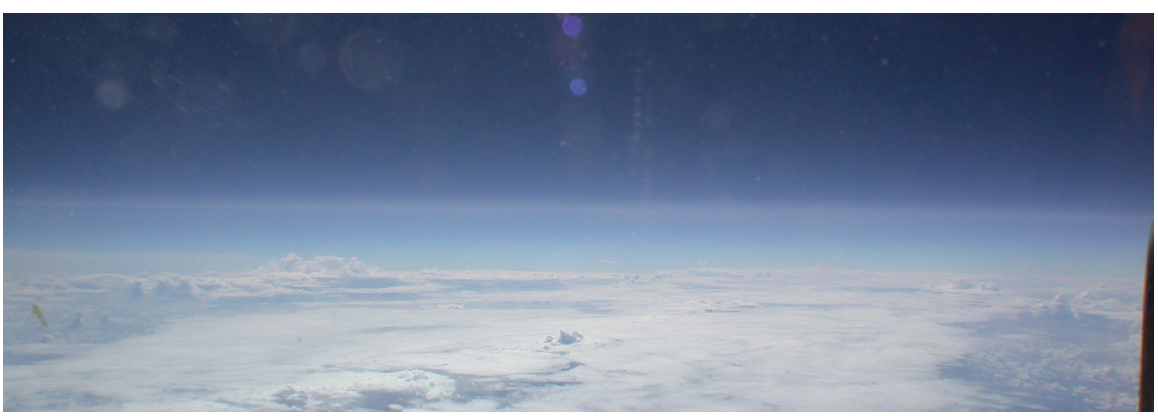

Figure 4.1. Photograph of a thin layer of cirrus clouds taken from the NASA WB-57F from an altitude of 60,000 feet on January 14, 2006. This extensive but thin layer of cirrus is not visible from the ground. Photo by John Bain (NASA JSC).

4.2.2.1 Cloud Physics Lidar (CPL)

In January 2006, the CPL instrument was part of the Costa Rica Aura Validation Experiment (CR-AVE). This experiment was based in San Jose, Costa Rica for the express purpose of validating instruments onboard the Aura satellite. Seven science flights were conducted to acquire high quality test data for the CloudSat and CALIPSO satellites using well characterized simulators for the primary satellite sensors. CloudSat and CALIPSO were subsequently launched in spring of 2006. For CR-AVE, the CPL was operated on the WB-57F aircraft. For more information on the CPL instrument, or for access to CPL data, visit http://cpl.gsfc.nasa.gov/ or contact Matthew McGill (matthew.j.mcgill@nasa.gov).

4.2.2.2 Cloud Radar System (CRS)

The CRS is a Doppler radar developed for autonomous operation in the NASA ER-2 high-altitude aircraft and for ground-based operation. It was flown for the first time during CR-AVE on the WB-57F aircraft. The goals for CPL and CRS were to prepare a remote sensing package for the CloudSat and CALIPSO satellites after their launch in Spring 2006. For further information on the CRS visit http://rsd.gsfc.nasa.gov/912/edop/crs_id_description.htm or contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.3 Tropical Warm Pool–International Cloud Experiment (TWP-ICE)

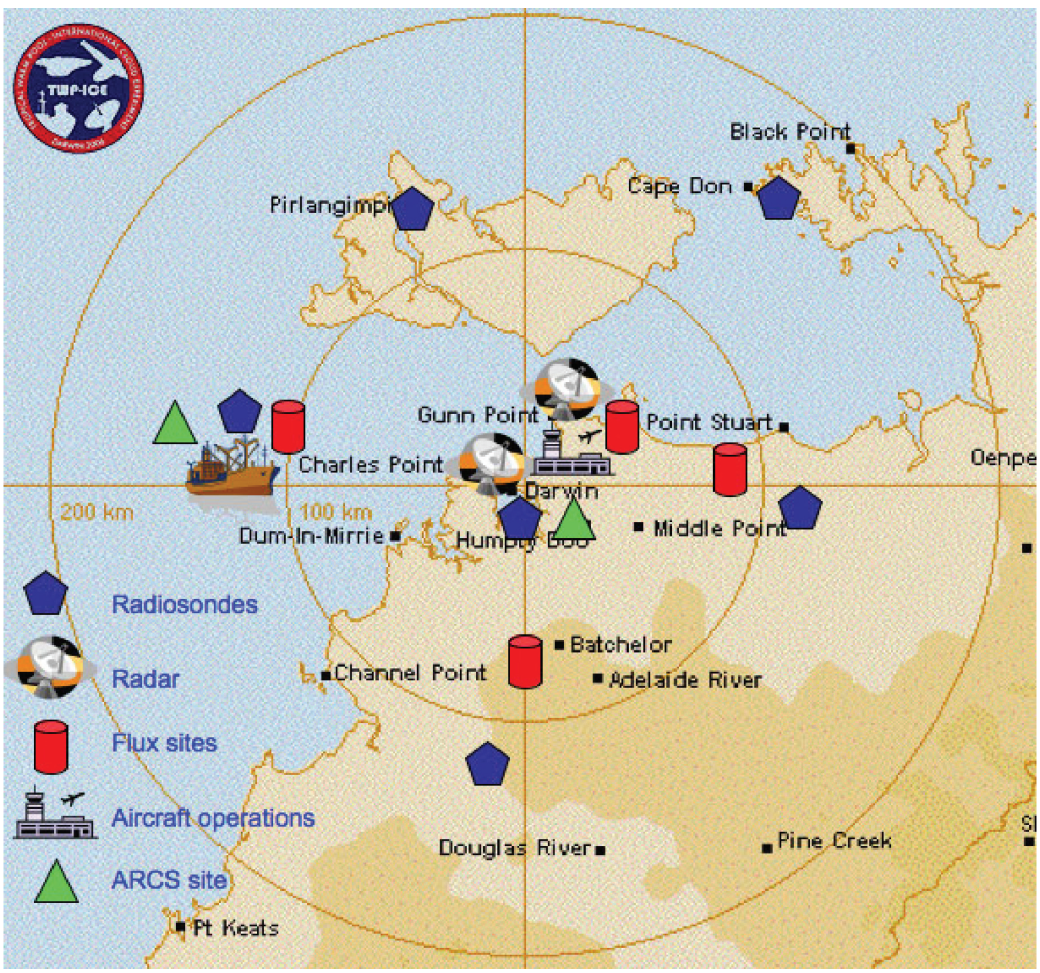

Figure 4.2. The map shows the extensive ground network of cloud sensing radar. Lidar, and passive instruments were located on a ship as well as several ground sites throughout the TWP-ICE experimental domain.

David Starr, Code 613.1, served on the Mission Management Team for TWP-ICE that took place in the area around Darwin, Australia in early 2006. Andy Ackerman, and Anne Fridlind, both Code 611 (GISS), participated in the in-field theory team. David Starr contributed to the daily mission planning and real-time operational execution of this complex airbone experiment which involved a fleet of 5 aircraft. The aim of the experiment was to examine convective cloud systems from their initial stages through to the decaying and thin high-level cirrus and measure their impact on the environment. The experiment design included an unprecedented array of soundings, research-grade volumetric radar coverage, and other information to support cloud-resolving and other modeling studies as well as *in situ* and remote sensing airborne observation platforms. This large multi-agency experiment involved substantial contributions from the following entities:

- U.S. Department of Energy, ARM Program;
- U.S. National Aeronautics and Space Administration (NASA);
- Australian Bureau of Meteorology (BoM); and
- Commonwealth Scientific and Industrial Research Organization (CSIRO)

A number of universities and a group sponsored by the European Union also contributed instrumentation to the experiment.

A key component of the field campaign was the fleet of aircraft including the Dornier for sampling aerosols and chemistry in the boundary layer, the Dimona for flux measurements in the boundary layer, the Egrett and Proteus for high-altitude *in situ* and remote sensing measurements, and a Twin Otter which carried lidar and radar for CloudSat and CALIPSO validation studies. The Egrett and Dornier comprised the European Union sponsored ACTIVE (Aerosol and Chemical Transport In tropical conVEction) component of TWP-ICE. The Proteus and Twin Otter were sponsored by ARM with support from the CloudSat and CALIPSO projects. Together, these aircraft collected measurements of cloud properties and the meteorological environment from the planetary boundary layer up to 15 km, often in-anvil at the upper levels. The airborne sampling was coordinated with observations from cloud sensing radar, lidar and passive instruments located at the ARM facility site, operated at Darwin by the BoM, and on a ship in the Timor Sea approximately 100 km northeast of Darwin. The experiment was a great success with data collected for a variety of convective systems and in upper tropospheric clouds at various stages of their lifecycle from freshly generated to quite aged. Cirrus outflow from both monsoon systems and highly continental systems were extensively sampled. In November, a post-experiment science workshop was held at GISS. The reported data quality was quite good and significant progress was being made on a number of key science issues such as characterizing differences in microphysical properties of cirrus based on age and nature of convective source.

For further information contact David Starr, David.Starr@nasa.gov.

4.2.4 Intercontinental Chemical Transport Experiment – Part B (INTEX-B) and Megacity Initiative: Local and Global Research Observations (MILAGRO)

The main mission goals of INTEX-B were to study the export of pollutants out of the Mexico City region, to study the transport of pollutants from Asia, across the Pacific Ocean to North America, and to provide data for the validation of Aura instrument products. The mission ran from March to May, 2006 and included local flights from three locations: Houston, TX, Honolulu, HI, and Anchorage, AK. The Houston, TX deployment coincided with the MILAGRO campaign in Mexico (see below). For mission details see: http://www-air.larc.nasa.gov/missions.htm.

Ken Pickering (Code 613.3) and Tom Kucsera (SSAI) developed, produced, and interpreted a set of trajectory- and satellite-based forecast products to aid in flight planning for the INTEX-B experiment. These products were run for all three deployments and were interpreted and presented to the flight planning team in the field.

Products included the OMI Aerosol Index (AI) observations and a forecast product predicting aerosol exposure based on a field of back trajectories run through the AI data. Lightning observations from a global network and a trajectory-based forecast of exposure to lightning NO_x emissions were also made available to the team. Other products included forecast meteorological fields from Goddard's Global Modeling and Assimilation Office (GMAO), a reverse-domain-fill forecast of potential vorticity, and maps of total column ozone and tropospheric NO_2 from OMI.

The Code 613.3 AROTAL instrument was deployed on the NASA/UND DC-8 aircraft (UND is University of North Dakota) for the INTEX-B mission. The AROTAL instrument makes vertical profile measurements of ozone, aerosols and temperature above the aircraft. For further information on this aspect of INTEX-B contact Tom McGee (Thomas.J.McGee@nasa.gov).

Lorraine Remer (Code 613.2) and D. Allen Chu (JCET/UMBC) joined the forecast team for INTEX-B, preparing satellite imagery and analysis for flight planning. Their particular specialty was the forecast of aerosol events using MODIS data. During the deployment in Anchorage, AK they noted several Asian dust events entering the Pacific study area and also an interesting biomass burning event from Siberia that moved over Scandinavia and into the Arctic. During the analysis phase Remer and Chu will use data collected during the deployments to make estimates of aerosol radiative effects and forcing.

Megacity Initiative: Local And Global Research Observations (MILAGRO) Mexico City, March 2006

The MILAGRO field campaign represents an umbrella initiative that encompassed simultaneous campaigns from NCAR, ASP/DOE, MIT, NASA and several Mexican agencies and universities. The campaign took place during March 2006, centered on Mexico City, but extended throughout central Mexico. The NASA component of MILAGRO was the first phase of INTEX-B. The objectives of the campaign were to characterize the pollutant exports of the world's second largest megacity (18 million people). Ground-based, airborne, and satellite measurements complemented an extensive modeling effort.

The Laboratory, in collaboration with UMBC, participated in making measurements on the ground and as part of NASA's payload on the J31 aircraft (PI: P. Russell of NASA/Ames). The composite image, Fig. 4.3, shows the Sky Research Jetstream-31 (J31) as it was deployed during the MILAGRO experiment in Mexico during March 2006.

The objectives of MILAGRO included characterizing the pollutant plume that originates in the greater Mexico City area and the evolution of that plume as it exits the basin. The J31 was just one of six aircraft participating in the experiment, along with three main ground sites, several auxiliary ground sites and several tethered balloons. Five of the aircraft, including the J31, were based in Veracruz on the east coast of Mexico.

The J31 was unique in that it was equipped to measure solar energy and how that energy is affected by the pollution and the Earth's surface. The aircraft carried six instruments. The Ames Airborne Tracking Sunphotometer-14 (AATS-14) provided total column spectral aerosol optical depth and precipitable water vapor, and vertical profiles of aerosol extinction and water vapor density. The Research Scanning Polarimeter (RSP) measured the spectral and polarized radiance from the surface and atmosphere beneath the plane. The Solar Spectral Flux Radiometer (SSFR) measured the upwelling and downwelling spectral hemispheric irradiance. The Cloud Absorption Radiometer (CAR) measured spectral and angular distribution of scattered light by clouds and aerosols. It also provided bidirectional reflectance of various surfaces, and imagery of cloud and Earth surface features. The Position and Orientation System (POS) and the Met Sensors and Navigation Data System (NavMet) provided useful information on aircraft position, orientation and meteorological variables.

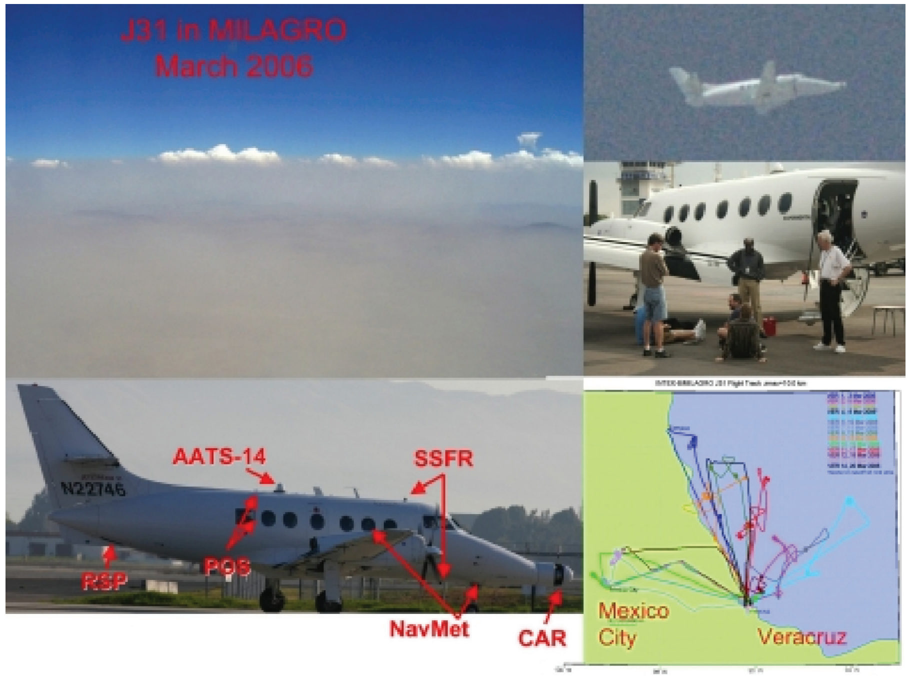

Figure 4.3. Remote Sensing Aircraft, J31, during MILAGRO. The images starting from the top left show the heavily polluted environment that was encountered in the basin north of Mexico City on March 19, 2006., the J31 scientists and engineers waiting to board the aircraft, the flight tracks of all of the J31's flights during MILAGRO, and instrument locations on the aircraft. Images were provided by Phil Russell (NASA/Ames) who was PI of the aircraft, Kirk Knobelspiesse (Columbia Univ.) and Dominik Cieslak (UMBC).

The Laboratory's participation was led by Lorraine Remer, J. Vanderlei Martins (JCET/UMBC), Michael King, and Charles Gatebe (GEST/UMBC). Our particular interests were to characterize the absorption properties of the aerosol, the extinction of the aerosol as a function of humidity, the bidirectional reflectance of the surface, especially the highly urban surface of Mexico City, and to test a new remote sensing technique for deriving aerosol absorption over ocean sun glint. We deployed instrumentation and team members at one of the MILAGRO sites to the northeast of Mexico City, but still within the caldera. We also deployed instrumentation at three sites along the Mexican east coast. The J31 flew 14 missions from the city of Veracruz, some over the ocean to intercept the outgoing pollution plume and some over Mexico City to characterize the pollution near the source and to characterize the bidirectional reflectance distribution function (BRDF) of the urban landscape.

In Fig. 4.4, the photograph in the background shows aged pollution from Mexico City over a ground-based station in the city of Pachuca, Hidalgo State, which is located about 150 km north of Mexico City. The relatively low visibility, fading the mountains in the background, is a result of the scattering of solar radiation by the aerosol particles in suspension in the atmosphere. These particles scatter and absorb solar radiation contributing to cooling the Earth's surface and potentially heating some atmospheric layers. These aerosols also act as cloud condensation nuclei, initiating the formation of cloud droplets in the Earth's atmosphere. The graph shows an example of the interaction between these aerosols and water vapor in the atmosphere measured with a humidified scattering/extinction cell during the March 2006 MILAGRO Field Experiment

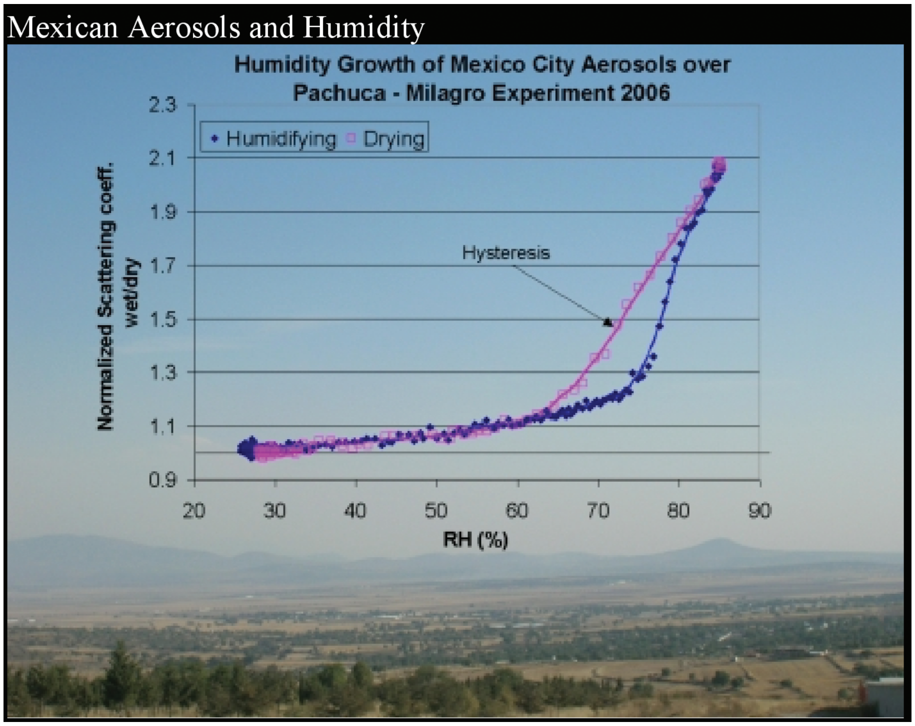

Figure 4.4. Growth of Mexico City aerosols vs. relative humidity superimposed on a picture of background pollution .

For further information contact Ken Pickering, Kenneth.E.Pickering@nasa.gov or Lorraine Remer, Lorraine.A.Remer@nasa.gov. For additional information on MILAGRO and the CAR instrument visit http://www.eol.ucar.edu/projects/milagro/ and http://car.gsfc.nasa.gov/data/.

4.2.5 Biomass-burning Aerosols in South East Asia: Smoke Impact Assessment Field Experiment (BASE-ASIA)

Biomass burning has been a regular practice for land clearing and land conversion in many countries, especially those in Africa, South America, and Southeast Asia. Southeast Asia, home to more than 60% of the world's population, is one of the fastest growing regions in population density and economic activity and is experiencing vital changes in land use and land cover. This leads to increases in fossil fuel, coal, and biomass burning with consequent increases in man-made aerosols in the atmosphere.

"Are Smoke Aerosols responsible for changing Cloud Life-Cycle and redistributing Fresh Water? *Since light-absorbing particles (e.g., smoke, soot, or black carbon) warm the atmosphere, they reduce surface evaporation and cut off convection, essential parts of the hydrologic cycle."*

In the spring of 2006, a joint U.S.-Thailand research group conducted the BASE-ASIA pilot study, seeking to better understand regional aerosol radiation forcing on the Earth-Atmosphere system. Participants include scientists from the U.S., NASA GSFC Laboratory for Atmospheres, Univ. Hawaii, Univ. Maryland; from Thailand, Chulalongkorn University, Bureau of Royal Rainmaking and Agricultural Aviation; and many individuals from the regions. Accurately assessing the impact of smoke aerosols on aerosol-cloud interactions requires continuous observations from satellites and networks of ground-based instruments as well as dedicated field experiments utilizing aircraft and ground-based instruments. Figure 4.5 illustrates the operations of BASE-ASIA, including the utilization of NASA's Terra, A-Train satellites and other satellite data sets in Southeast Asia, NASA GSFC hyperspectral imagers (solar and thermal) flown aboard Thai's rainmaking fleet (CASA-100 aircraft, based at Khora, Thailand), and GSFC's SMART (Surface-sensing Measurements for Atmospheric Radiative Transfer) & COMMIT (Chemical, Optical, Microphysical Measurements of *In situ* Troposphere) mobile observatory (http://smart-commit.gsfc.nasa.gov/) and COPAA (Chemistry & Optical Properties of Absorbing Aerosols) facility from University of Hawaii deployed in the middle of agricultural fields at Phimai, Thailand. During the peak-burning season (e.g., February–March–April), a frequently observed phenomenon is smoke-induced clouds (Fig. 4.5), even in small-scale burning. On a cloud-free day (visually in the zenith direction), the temperature profiles (panel g, blue line for noontime, red for afternoon) often depict one (noontime) or multiple (afternoon) inversion layers. It may be that local biomass-burning practices are relatively more active in the afternoon, leading to elevated levels of light-absorbing aerosols in the boundary layer and a subsequent warming within such layers. A challenging task in understanding aerosol-cloud interactions is underway by combining these surface *in situ* and remote-sensing measurements, aircraft and satellite observations, together with modeling efforts. For further information, contact Si-Chee Tsay (si-chee.tsay@nasa.gov).

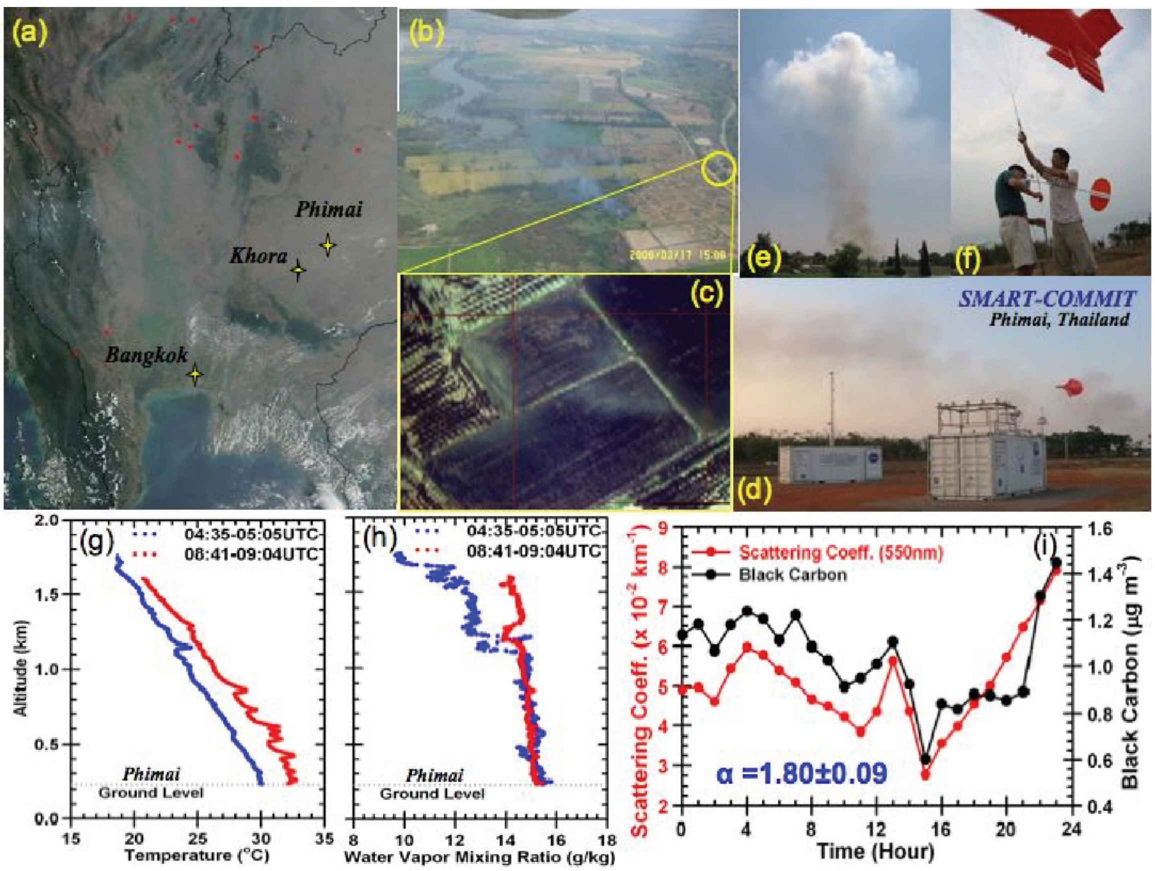

Figure 4.5. (a) Satellite image (Terra/MODIS for red, 0.66 µm; green, 0.55 µm; blue, 0.47 µm) depicts active fires (red dots) and extensive layer of haze/smoke aerosols over Southeast Asia. (b, c) A GSFC solar hyperspectral imager explores spectral and spatial features of biomass burning. (d) GSFC's SMART-COMMIT mobile observatory was deployed in the middle of agricultural fields at Phimai, Thailand, from the pre-burning, peak-burning, to the pre-monsoon seasons. (e, f, g, h, i).

Many attempts were made to investigate the atmospheric state parameters (e.g., pressure, temperature, water vapor, and wind) by launching tethered balloons (up to 2 km within 30 min) in the boundary layer, as well as the optical, microphysical, and chemical measurements (e.g., aerosol optical depth, Ångström exponent, black carbon mass concentration) associated with frequently observed smoke-induced clouds.

4.2.6 Sodankylä Total Column Ozone Intercomparison (SAUNA)

Validation of ground-based and satellite total ozone measurements are usually performed under ideal measurements conditions at mid-latitudes where total ozone is near 300 DU. In general, agreement between ground-based instruments is within 2%, giving confidence to the methods and algorithms under these conditions. However, total column ozone retrievals at high latitudes show persistent differences of 5–10%, especially under conditions of low sun, high total column ozone (> 400DU) and high column variability. Satellite and ground-based measurements must be compared under a greater variety of ozone column amounts and profile shapes if such differences are to be resolved.

The objective of the Sodankylä Total Column Ozone Intercomparison was to assess the comparative performance of the ground-based instruments and algorithms that measure total column ozone at large solar zenith angles and high total column ozone amounts. SAUNA was organized by the NASA GSFC Laboratory for Atmospheres, in collaboration with the Finnish Meteorological Institute Arctic Research Center (FMI-ARC) and the European Space Agency (ESA-ESRIN), and involved 30 participants from 10 institutions in 9 countries. A list of participants and instruments is given in Table 4.2. The SAUNA campaign was carried out from March 20 to April 14 at the FMI-ARC located 120 km north of the Arctic Circle at Sodankylä, Finland (Figure 4.6).

Table 4.2: List of SAUNA Instruments and Principal Investigators.

Instrument	Principal Investigator	Affiliation
Brewer: single monochromator	E. Kyrö	FMI-ARC (Finland)
Brewer: 1 single (World standard), 1 double	T. McElroy	MSC (Canada)
Brewer: double	A. Cede R. McPeters	NASA GSFC (USA)
Brewer: 1 double (European Standard)	A. Redondas E. Cuevas	INM-Izana (Spain)
Dobson (Traveling standard)	R. Evans	NOAA/ESRL/GMD (USA)
Dobson (European standard)	U. Koehler	DWD-MOHp (Germany)
DOASs: 1 UV, 1 vis, 1 miniDOAS	M. van Roozendael	BIRA-IASB (Belgium)
miniDOAS	E. Brinksma	KNMI (Netherlands)
SAOZ (permanently at FMI-ARC)	F. Goutail	CNRS-SA (France)
STROZ-LITE LIDAR (NDSC standard)	T. McGee	NASA-GSFC (USA)
Ozonesondes	R. Kivi B.R. Bojkov	FMI-ARC (Finland) NASA-GSFC (USA)

Figure 4.6. Finland and the location of Sodankylä, 120 km north of the Arctic Circle (67.37°N, 26.63°E).

The early springtime at this high latitude provides the ideal large solar zenith angles for the mission, and total ozone is consistently higher than 400 DU over Sodankylä at this time of year. The timing of the SAUNA mission took advantage of these geophysical conditions.

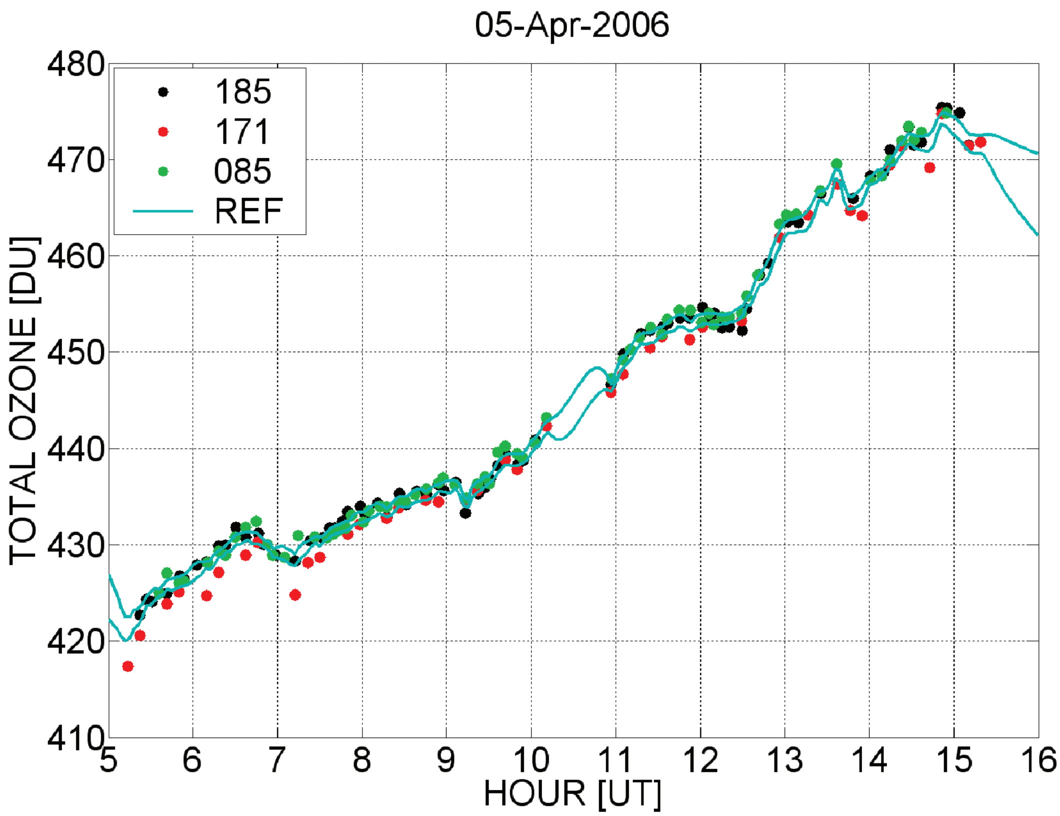

Figure 4.7. Measurements of the three participating Brewer double monochromator spectrophotometers as seen for April 5, 2006. This high column increase through the course of the day was typical for the SAUNA campaign.

A typical measurement day is depicted in Figure 4.7 showing a variability of 60 DU in 9 hours. Observations made by space based instruments aboard several satellites are tightly integrated into the intercomparison strategy of the mission as well. The effect of ozone and temperature profile on total column measurements will also be explored using LIDAR and ozone sonde observations. The Laboratory STROZ Lidar participated in this campaign to provide stratospheric vertical profiles of ozone and temperature during each of the clear nights during the campaign. Ozone and temperature profiles were retrieved during six nights, and were compared to the profiles from sondes launched from Sodankylä (although these were not always coincident in time.) Figure 4.8 shows the results of these lidar/sonde comparisons. The overall mean difference was 0.86% ± 0.28%. The majority of the difference is due to the extreme variability of the atmosphere and the different measurement geometries.

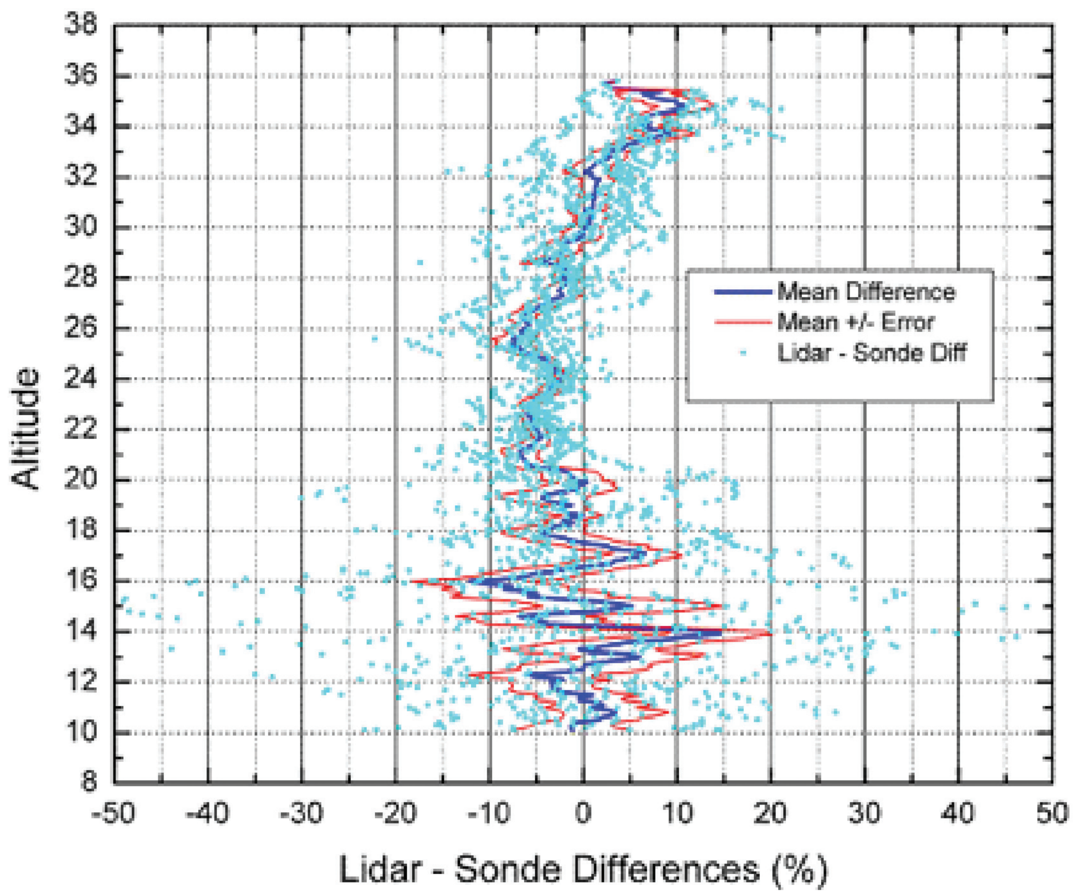

Figure 4.8. Lidar/Sonde differences in O_3 profiles during SAUNA.

The scientific findings from the SAUNA mission should improve the absolute accuracy of historic and future total ozone observations made under the extreme conditions of high ozone and large solar zenith angles. A data workshop was held in November 2006 and consensus was reached to redeploy at Sodankylä in February 2007 to focus on the profile shape dependence of the ground-based and satellite algorithms at very large solar zenith angles (> 80 deg.). In addition to the ground-based instruments of the first SAUNA campaign, intensive STROZ Lidar measurements and about 50 ozonesondes will be launched during the 4 week SAUNA-2 campaign.

For further information on SAUNA contact Bojan R. Bojkov (UMBC/GEST, Bojan.Bojkov@gsfc.nasa.gov) and for information on the STROZ Lidar, contact Tom McGee, Thomas.J.McGee@nasa.gov).

4.2.7 NASA African Monsoon Multidisciplinary Analysis (NAMMA)

This mission, running from August 15 to mid-September, examined the formation and evolution of tropical hurricanes in the eastern and central Atlantic and their impact on the U.S. East Coast, the composition and structure of the Saharan Air Layer (SAL), and whether aerosols affect cloud precipitation and influence cyclone development. During the 2006 hurricane season, a group of scientists spent a month in Cape Verde, a republic of 10 small islands off the western coast of Africa, to learn more about the birth of these storms. Some of most intense hurricanes that cause serious influence over the East Coast and Caribbean Islands originate from African Easterly Wave(s) (AEWs), which are disturbances moving westward from the African continent over the

Atlantic Ocean. Only a limited number of disturbances grow into hurricanes. How these disturbances become hurricanes, or more generally tropical cyclones, is not well known. The SAL, a warm, dry and often dust-laden air mass, is believed to influence tropical cyclones according to some theories. This intrigues scientists studying the structure and composition of the SAL and its interaction with AEWs. Several instruments participating in NAMMA and a sampling of some of their results are shown in Figure 4.9.

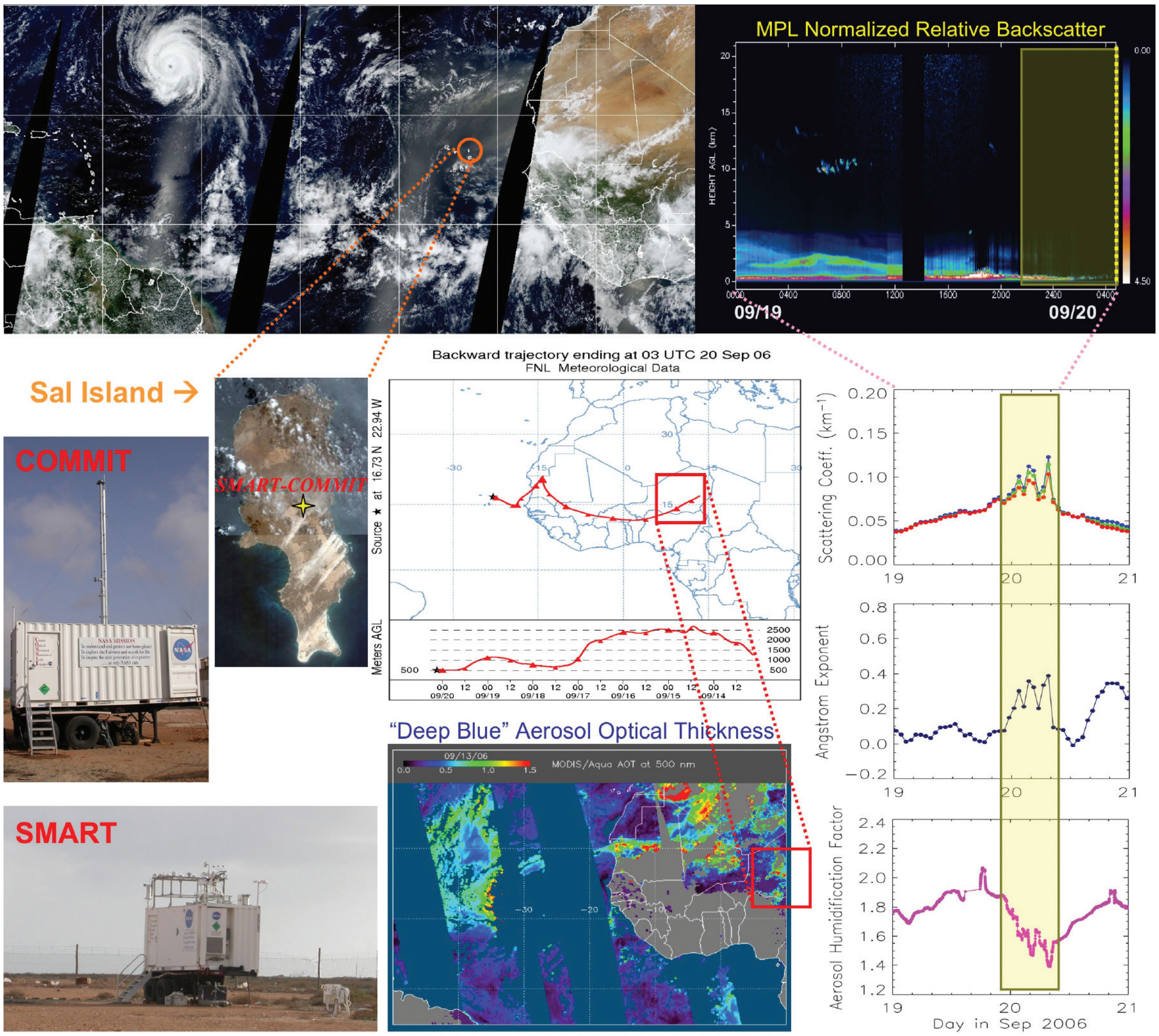

Figure 4.9. Schematic of Laboratory instruments participating in the NAMMA field campaign.

Two mobile laboratories, SMART (Surface-sensing Measurements for Atmospheric Radiative Transfer; bottom-left) and COMMIT (Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere; middle-left) were deployed at Sal Island, Cape Verde to continuously monitor the structure and composition of the atmosphere in the major path of the SAL and the AEWs.

Hurricane Helene in the North Atlantic Ocean and a dust storm passing over Sal Island were observed by NASA's Terra/MODIS satellite (Top-left). When Saharan dust descended down near the surface, its physical and chemical properties were captured by SMART-COMMIT. An instrument in SMART, Micro-Pulse Lidar (MPL), which continuously measures the vertical distribution of atmospheric particulates, caught such an episode (top-right image). Backward trajectory analysis, which traces a parcel of air mass back to find out where it came from, suggests the dust aerosol layer seen by the MPL may have originated from a dust storm over Niger (middle-center). “Deep Blue” satellite-based aerosol retrievals to infer the optical properties of aerosols also support this result from the backward trajectory analysis (bottom-center). The three graphs in the bottom-right show measurements from COMMIT at the near surface (10 meter), which represent the amount of aerosols (scattering coefficient), their size (Angstrom exponent; the smaller values, the larger aerosols), and a measure of their capability to take up water vapor and grow in size as humidity increases (aerosol humidification factor, ratio of scattering coefficients measured at two distinct relative humidity values—normally at 85% and 40%), respectively. These graphs indicate changes in aerosol optical properties as dust particles increase with time in the marine boundary layer where sea-salt particles would be a dominant type of aerosol otherwise. These preliminary measurements will be used to characterize properties of dust and the SAL to help understand their interactions with AEWs and their impact on hurricane genesis.

NASA’s DC-8 medium altitude research aircraft also participated in the NAMMA investigations. Sensors on-board the aircraft measured cloud and particle sizes and shapes, wind speed and direction, rainfall rates, atmospheric temperature, pressure and relative humidity. The DC-8 aircraft made 13 research missions that sampled 7 different waves/circulations, most of them for 2 different days. They included about 3 developing and 4 non-developing systems. The last system studied developed into Hurricane Helene. There were a number of dedicated missions or modules that addressed microphysics and SAL issues.

For further information contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.8 Scout-O3 UV: Total Column NO_2

Measurements of direct-sun irradiances were made at the city of Thessaloniki, in Greece (latitude 40.5° North, longitude 22.9° East). The instrument was set up on an elevated platform on top of the Thessaloniki University Physics building, about 60 meters above sea level, as part of the Greek-EU Scout-O3 campaign in July 2006. After instrument setup, a Brewer, PAN-1, Ultraviolet Multifilter Rotating Shadowband Radiometer (UV-MFRSR), and a CIMEL made measurements throughout the day from July 13 to 23 under all sky conditions. All four instruments measured 2 out of 3 aerosol parameters (optical depth, Ångstrom coefficient, and absorption coefficient) in different ways, the Brewer and PAN-1 measured NO_2, PAN-1 and the CIMEL measured H_2O, and the Brewer and the UV-MFRSR measured O_3. The measurements of interest are those mainly related to NO_2, with the measurements of other gases and aerosols serving as auxiliary data. The auxiliary data permits us to remove Rayleigh scattering, aerosol effects, and ozone absorption, leaving the NO_2 residual in the data.

Recent satellite measurements have shown the relationship between industrial activity and the apparent amount of NO_2 in the atmosphere. However, comparisons between satellite NO_2 column amounts obtained from the Aura/OMI spacecraft instrument with accurate ground-based direct-sun measurements made with a Brewer double monochromator show a 50% OMI underestimate of NO_2 in moderately polluted areas like Greenbelt, MD and Thessaloniki, Greece. We have used a new technique based on DS-DOAS (Direct Sun–Differential Optical Absorption Spectroscopy) to retrieve ground-based measurements of NO_2 at high precision (0.01 DU) and good accuracy (0.1 DU). The measurements are made using a newly developed portable system (PANDORA) based on a small temperature stabilized commercial 1024 element CMOS-detector spectrometer connected by fiber optic cable to a 1.6° field of view collimator and filter wheel assembly. A precision pointing mechanism, 0.01°, is used to track the sun. The spectrometer simultaneously measures sun irradiances $I(\lambda)$ from 265 to 500 nm at $\Delta\lambda = 0.4$ nm spectral resolution with ~3 pixels per 0.4 nm. We average 2500 cloud-free spectra obtained over 20 seconds to obtain high signal to noise. New data were obtained from a field campaign in Thessaloniki, Greece during July 2006 that have a clear-sky precision of 0.01 DU of NO_2, which is sufficient to track minute by minute changes in column NO_2 throughout each day with typical values of 0.5 to 3 DU. Since PANDORA NO_2 measurements can be made in the presence of light to moderate clouds with reduced precision (~0.2 DU for moderate cloud cover), a nearly continuous record can be obtained, which is important for matching the OMI overpass time.

The daily NO_2 data for the period July 14 to 24, 2006 are shown (Figure 4.10) for both the Brewer and for PAN-1. The Brewer data are obtained approximately every 20 minutes while the PAN-1 data are obtained every 2 minutes. Some of the days when the data were obtained were partly cloudy, with the sun going in and out of thin clouds. Thin clouds do not affect the PAN-1 data, since the wavelengths are obtained simultaneously. The same is not true for the Brewer, where the 6 wavelengths are obtained sequentially over a short interval. The result is additional scatter in the Brewer estimates of NO_2 as is clearly shown in Figure 4.10. This effect is particularly seen on Saturday July 15 where the PAN-1 data are highly correlated from measurement to measurement, while the Brewer data show substantial random scatter that is greater than their estimated error. It is important to have time resolved measurements to correspond to the OMI overpass time to remove the bias effect of the hourly variation in NO_2 for observations at other times, especially early morning observations (DOAS). Current satellite measurements have shown that there is a great deal of spatial variability in NO_2 amounts because of its relatively short chemical lifetime and its dependence on proximity to sources of NO_2, mostly automobiles and power plants.

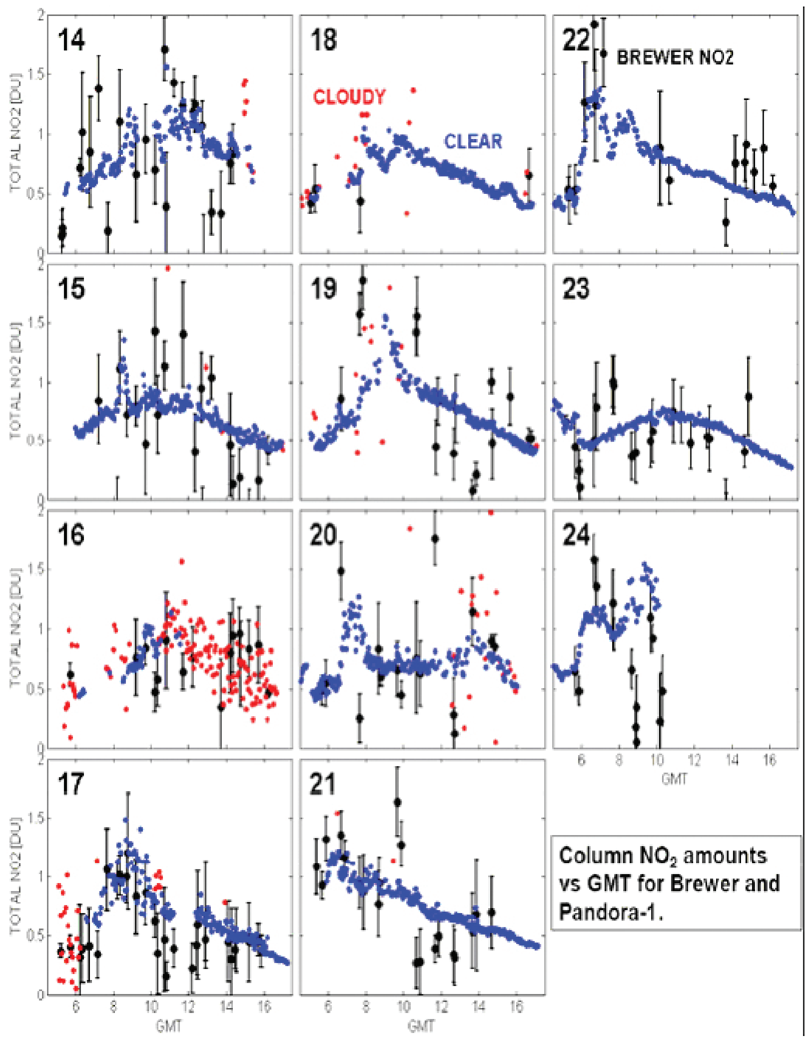

Figure 4.10. NO_2 daily course for Friday July 14 to Monday July 24, 2006 at Thessaloniki, Greece as a function of GMT (Local time = GMT + 3). The blue dots represent clear-sky PAN-1 data and black dots and error bars are from the Brewer spectrometer. Red dots indicate the presence of clouds. The precision of the PAN-1 NO_2 values is 0.01 DU. The OMI overpass time is about 13:30 local time or 10:30 GMT.

For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

4.2.9 CALIPSO-CloudSat Validation Experiment (CC-VEx)

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations satellite (CALIPSO)-CloudSat Validation Experiment (CC-VEx) was conducted over the southeastern United States and adjacent waters from July 26 to August 14, 2006. The GSFC Cloud Physics Lidar (CPL) and Cloud Radar System (CRS) were flown on the high-altitude ER-2 aircraft for validation of the newly-launched CALIPSO and CloudSat satellites. The mission was conducted from Warner Robins Air Force Base in Warner Robins, GA to enable flights over a variety of cloud scenes, including sub-tropical cirrus off the coast of Florida. A total of 13 satellite underflights were obtained (4 were night flights to ascertain minimum detectable signal levels). The MODIS Airborne Simulator (MAS) was also part of the ER-2 payload. The CPL is a primary validation tool (nearly exact satellite sensor simulator) for the CALIPSO lidar and the CRS is a primary validation tool for the CloudSat radar.

This was a joint validation mission lead by LaRC (CALIPSO) and JPL/Colorado State (CloudSat) with participation by GSFC, DFRC, and others. All mission requirements were met.

The following figures, Figures 4.11, 4.12, and 4.13 provide additional details.

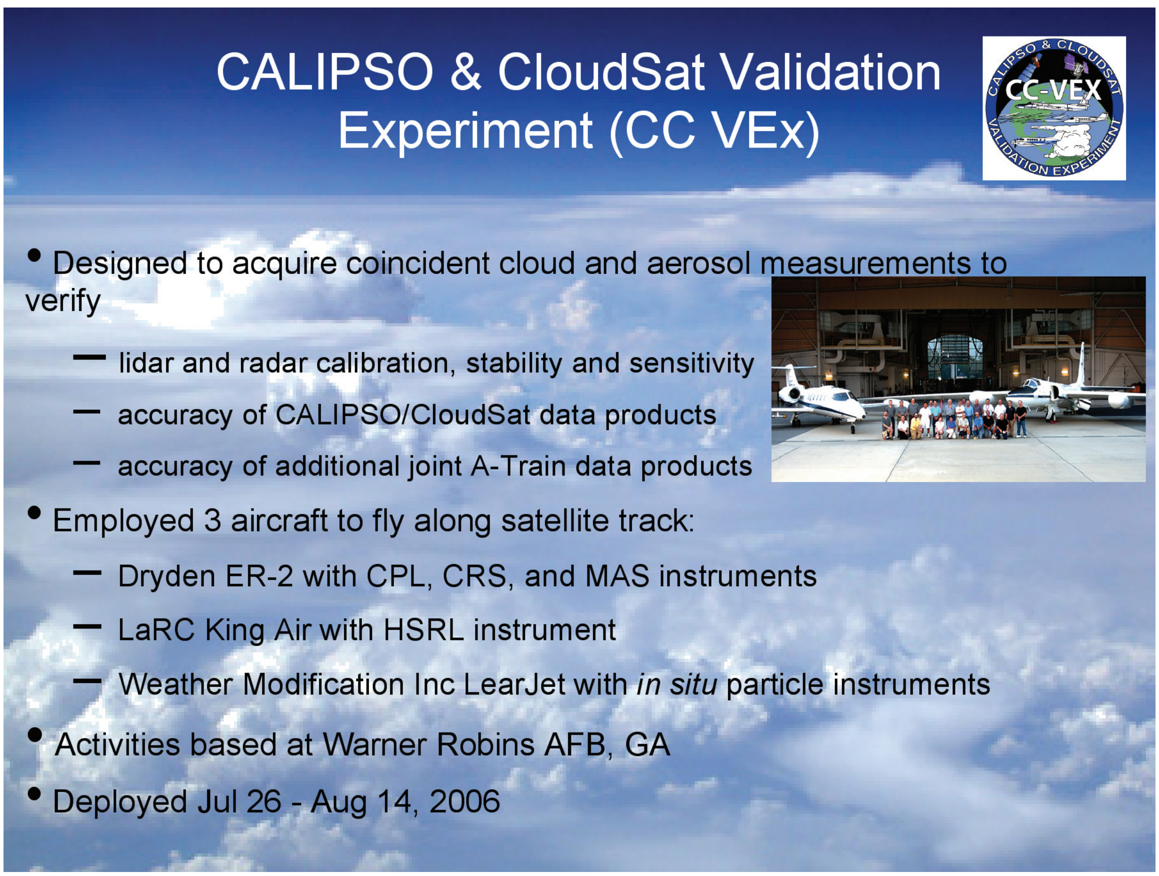

Figure 4.11. Overview of the CC-VEx objectives. The inset shows CC-VEx participants and two aircraft based at Warner Robins AFB, GA. The NASA ER-2, housing the CRS, CPL, and MAS, is on the right. The WMI Learjet, which carried various cloud probes for in situ sampling is on the left.

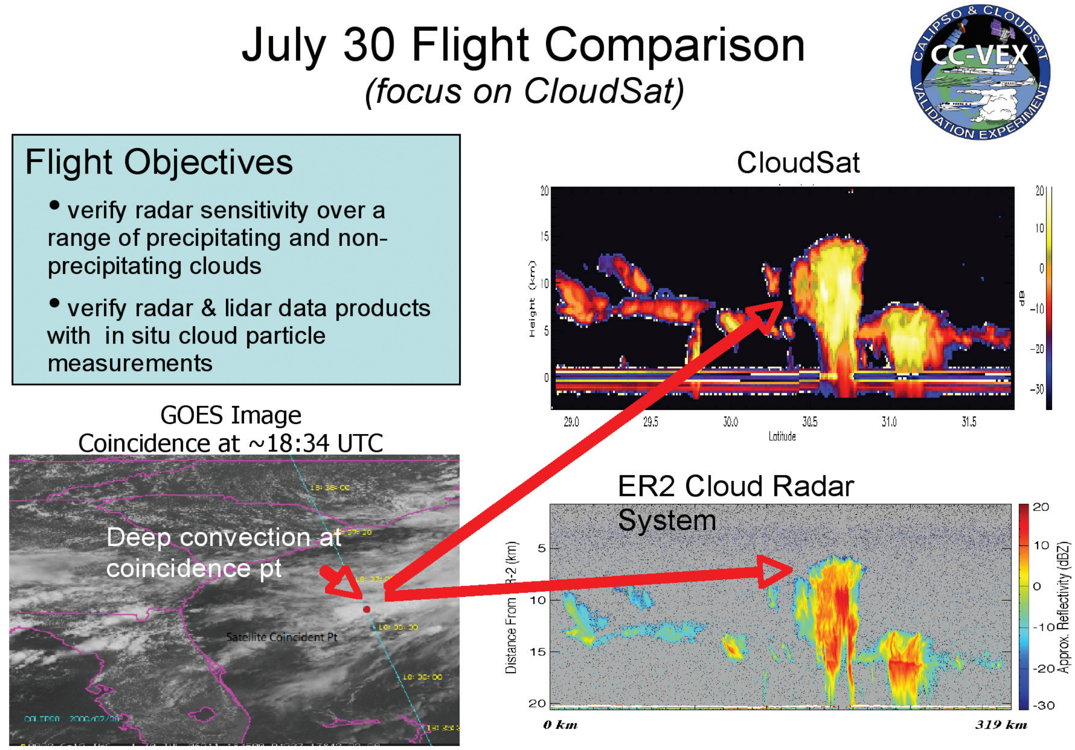

Figure 4.12. Comparison of CRS reflectivity with results from the CloudSat Cloud Profiling Radar. The satellite coincidence point is shown in the image at the lower left of the figure.

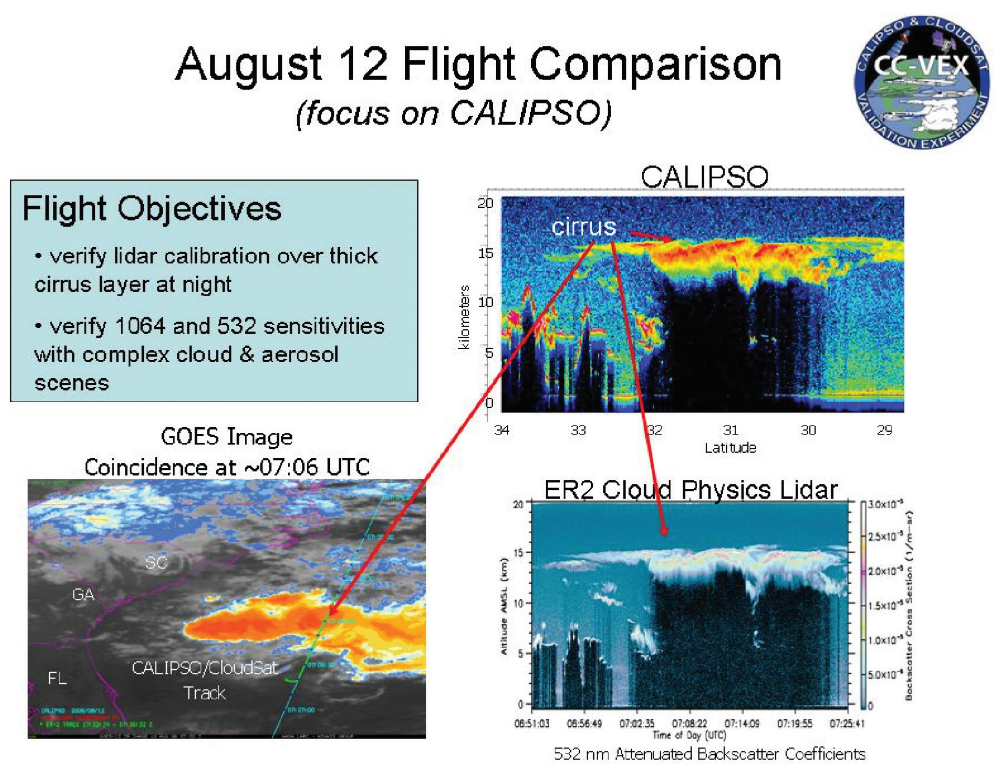

Figure 4.13. Comparison of the CPL 532 nm attenuated backscatter coefficients with results from the primary CALIPSO sensor, Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP).

For furthe information on the CPL instrument or for access to CPL data contact Matt McGill, Matthew,J,McGill@nasa.gov. For further information on the CRS instrument or for access to CRS data contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.10 Water Vapor Validation Experiment–Satellite/Sondes (WAVES)

The WAVES 2006 field campaign took place at the Howard University Research Campus in Beltsville, MD from July 7 to August 10. The field campaign goals were to:

- Acquire a statistically robust set of summer time measurements of atmospheric water vapor, aerosols and trace gases for Aura/Aqua satellite retrieval assessment.
- Inter-compare balloon-borne sensors (vapor and temperature) with ground-based lidars
- Assess the Tropospheric Emission Spectrometer (TES) ozone algorithm using ozonesondes
- Characterize sub-pixel water and aerosol variability
- Compare Penn State Nittany Atmospheric Trailer and Integrated Validation Experiment (NATIVE) aerosol and trace gas measurements with Maryland Department of the Environment (MDE).
- Characterize the daytime/nighttime aerosol and water vapor measurements from the new HU Raman Lidar.
- Study the performance of the National Weather Service (NWS) Radiosonde Replacement System (RRS)

The operations include intensive observations by multiple radiosonde/ozonesonde sensors and several lidar systems during overpasses of the Aura satellite. Lidar measurements are acquired by four lidar systems: NASA GSFC Scanning Raman Lidar (SRL), NASA GSFC Aerosol/Temperature Lidar (ATL), a Micropulse Lidar from Penn State, and Howard University Raman Lidar (HRL). Coordinated lidar measurements took place as well with the University of Maryland, Baltimore County (backscatter and Raman lidars) in order to provide information about the spatial variability of the aerosol and water vapor. In addition to the lidar/radiosondes operations, continuous measurements were taken by a 31m instrumented tower (temperature, flux, wind etc.), various broadband and spectral radiometers, microwave radiometer, Doppler C-band radar (Fox TV Channel 5), chemical and aerosol measurements, a wind profiler operated by the Maryland Department of Environment (MDE), a sun photometer (USDA), and a Suominet GPS system. A total of about 14 graduates, 7 undergraduates and many scientists from 16 institutions participated in the field work. A further description of student involvement in WAVES is contained in Section 6, Education and Outreach.

For further information contact Belay Demoz, Belay.B.Demoz@nasa.gov.

4.2.11 Measurements Of Humidity in the Atmosphere and Validation Experiment (MOHAVE)

The Aerosol and Temperature Lidar was deployed to JPL's Table Mountain facility for a water vapor measurements campaign during October 2006. The main goal was to validate lidar measurements of water vapor into the stratosphere. Three lidars were involved in this campaign as well as a Cryogenic Frost point Hygrometer (CFH) and standard Vaisala RS-92 radiosondes. The campaign discovered that all three of these lidars had a fluorescence issue, which became apparent at very low water vapor concentrations. The mechanisms for the fluorescence were not all the same, and the cause of the fluorescence was discovered for each lidar. After mechanical modifications are made, a second MOHAVE campaign is planned for September 2007.

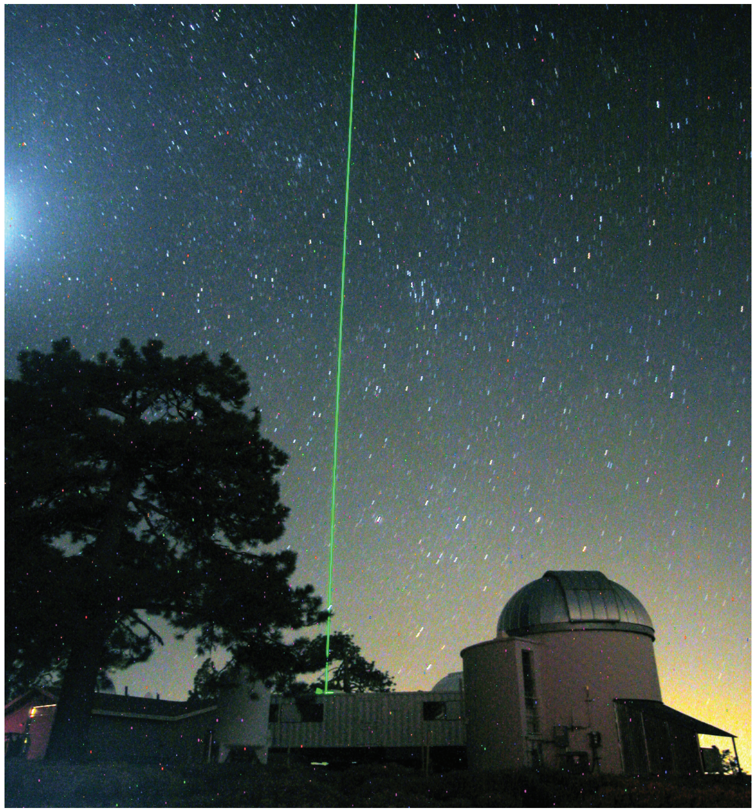

Figure 4.14. AT Lidar in action at JPL's Table Mountain facility.

For further information contact Tom McGee (Thomas.J.McGee@nasa.gov).

4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns are used directly in scientific studies. Some of this data, plus data from additional sources, is arranged into data sets useful for studying various atmospheric phenomena. Some major data sets are described in the following paragraphs.

4.3.1 50-Year Chemical Transport Model (CTM) Output

A 50-year simulation of stratospheric constituent evolution has been completed using the Code 613.3 three-dimensional (3-D) chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N_2O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine (1979 source gases) and low chlorine (1970 levels) and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of both interannual variability and a trend in the residual circulation in the input meteorological fields. The model output from all simulations is available on the Code 613.3 science system; software to read the output is also available. Although the CTM itself is run at 2° × 2.5° latitude/longitude horizontal resolution; the output is stored at 4° × 5° latitude/longitude. Higher resolution files are available from UniTree, the Code 606.2 archive. The model output stored on the science system is for six days each month; daily fields are saved on UniTree. Details about this and other CTM simulations are available from the Code 613.3 Web site at http://code916.gsfc.nasa.gov/Public/Modelling/3D/exp.html, which provides information about the various simulations.

Output from the three-dimensional Chemistry and General Circulation Model (CGCM) is also available on the Code 613.3 science system. Like the CTM simulations, these include boundary conditions that are specified for various trace gases. The simulations use different data sets (some observed, some model output) for the ocean temperatures. Readers for this output, a description of the files that are available, and some details of the simulations are found on http://hyperion.gsfc.nasa.gov/Personnel/people/Frith/webdir/GEOSCCM/gcm_data_transfer.html. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

4.3.2 Global Precipitation

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing climatic fluctuations and trends on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) has established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory are leading the GPCP effort to merge data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges, to produce research-quality estimates of global precipitation.

The GPCP data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at NOAA's National Climatic Data Center in Asheville, North Carolina, and at the Goddard Distributed Active Archive Center (DAAC). Evaluation is ongoing for this long-term data set in the context of climatology, El Niño Southern Oscillation (ENSO)-related variations, and regional and global trends. The nine-year TRMM data set is being used in the assessment of the longer GPCP data set. A daily, globally complete analysis of precipitation is also being produced by Laboratory scientists for GPCP for the period 1997 to the present and is available from the archives.

An even finer time resolution, a TRMM-based quasi-global, 3-hour resolution rainfall analysis, the TRMM Multi-satellite Precipitation Analysis (TMPA) is available from the Goddard DAAC for the period of January 1998 to the present. This product uses TRMM data to calibrate or adjust rainfall estimates from other satellite data and combines these estimates into rainfall maps at a frequency of every 3 hours at a spatial resolution of 0.25° latitude-longitude. A real-time version of this analysis is available through the TRMM Web site. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.3.3 Merged TOMS/SBUV Data Set

We have updated our merged satellite total ozone data set through late July of 2006. We have transferred the calibration from the original six satellite instruments to the current instrument NOAA 16 SBUV/2. We also have a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. We now have a preliminary data set that merges the measurements made by the OMI instrument on Aura. This will be made available to the public in early 2007. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

4.3.4 Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS operational Atmosphere Team algorithms produce both Level-2 (pixel-level or swath data) and Level-3 (gridded) products. There are six categories of Level-2 and Level-3 MODIS products collected from the Terra and Aqua platforms. Starting in April 2006, a new processing stream (referred to as "Collection 5") began. Further details on this new MODIS data processing effort, which includes significant algorithm updates and enhancements, are discussed in Section 5.4.1.

The Level-2 product files are grouped by Cloud Mask, Cloud, Aerosol, Precipitable Water, and Atmospheric Profile geophysical retrievals. In addition, a joint Atmosphere Team file contains a spatial sample of the more popular Level-2 retrievals. Level-3 MODIS Atmosphere products provide statistics on a 1° × 1° global grid and are produced for daily, eight-day, and monthly time periods.

Level-2 Products

The Aerosol Product provides aerosol optical thickness over the oceans globally and over a portion of the continents. Further, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. Level-2 aerosol retrievals are at the spatial resolution of a 10×10, 1 km (at nadir) pixel array.

The Precipitable Water Product consists of two-column water vapor retrievals. During the daytime, a near-infrared algorithm is applied over clear land areas, ocean sun glint areas, and above clouds over both land and ocean. An infrared algorithm used in deriving atmospheric profiles is also applied both day and night.

The Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties. Cloud optical thickness, effective particle radius, and water path are derived at a 1 km resolution using MODIS visible through mid-wave infrared channel observations. Cloud-top temperature, pressure, and effective emissivity are produced by infrared retrieval methods, both day and night, at a 5×5, 1 km pixel resolution. Cloud thermodynamic phase is derived from a combination of techniques and spectral bands. Finally, the MODIS Cloud Product includes an estimate of cirrus reflectance in the visible at a 1 km pixel resolution; these retrievals are useful for removing cirrus scattering effects from the land-surface reflectance product.

The Atmospheric Profile Product consists of several parameters: total column ozone, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a 5×5, 1 km pixel resolution when a 5×5 region is suitably cloud free.

The Cloud Mask Product indicates to what extent a given instrument field of view (FOV) of the Earth's surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice/snow, and sun glint contamination.

The Joint Atmosphere Product contains a subset of key parameters gleaned from the complete set of operational Level-2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere Product cover a full set of high-interest parameters produced by the MODIS Atmosphere Group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

Level-3 Products

The Level-3 MODIS Atmosphere Daily Global Product contains roughly 600 statistical data sets, which are derived from approximately 80 scientific parameters from four Level-2 MODIS Atmosphere Products: Aerosol, Water Vapor, Cloud, and Atmospheric Profile. Statistics are sorted into 1° × 1° cells on an equal-angle grid that spans 24 hours (0000 to 2400 UTC). A range of statistical quantities is computed, depending on the parameter being considered. In addition to simple statistics, the Level-3 files include a variety of one- and two-dimensional histograms. Similarly, the Level-3 Eight-Day and Monthly Global Product contain roughly 800 statistical data sets that are derived from the Level-3 Daily and Eight-Day products, respectively.

For further information, contact Steven Platnick (Steven.Platnick@nasa.gov) or visit the MODIS Web site at http://modis-atmos.gsfc.nasa.gov/.

4.3.5 MPLNET Data Sets

The Micro-Pulse Lidar Network (MPLNET) is composed of ground-based lidar systems co-located with sun-sky photometer sites in the NASA AERONET. The MPLNET project uses the MPL system, a compact and eye-safe lidar capable of determining the range of aerosols and clouds continuously in an autonomous fashion. The unique capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. These types of observations are required for several NASA satellite validation programs, and are also a high priority in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The combined lidar and sun photometer measurements are able to produce quantitative aerosol and cloud products such as optical depth, sky radiance, vertical structure, and extinction profiles. MPLNET results have contributed to studies of dust, biomass, marine, and continental aerosol properties, the effects of soot on cloud formation, aerosol transport processes, and polar clouds and snow. MPLNET sites served as ground calibration/validation for NASA's first satellite lidar, the Geoscience Laser Altimeter System (GLAS), and also provide validation for the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) in the A-Train. MPLNET data has also been used to validate results from passive NASA satellite sensors such as MODIS, the Multi-Angle Imaging Spectroradiometer (MISR), and TOMS.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: three in the U.S., three in Asia, two in Antarctica, one in the Arctic, and one off the west coast of Africa. Data from several of the sites are already publicly available on our Web site, and the remaining sites will soon be public after the calibrations are completed (data is being acquired offline in the interim). Older data sets from 14 field campaign sites remain available as well. Planning is underway for future sites in 2007, including additional sites in the U.S., Asia, the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East.

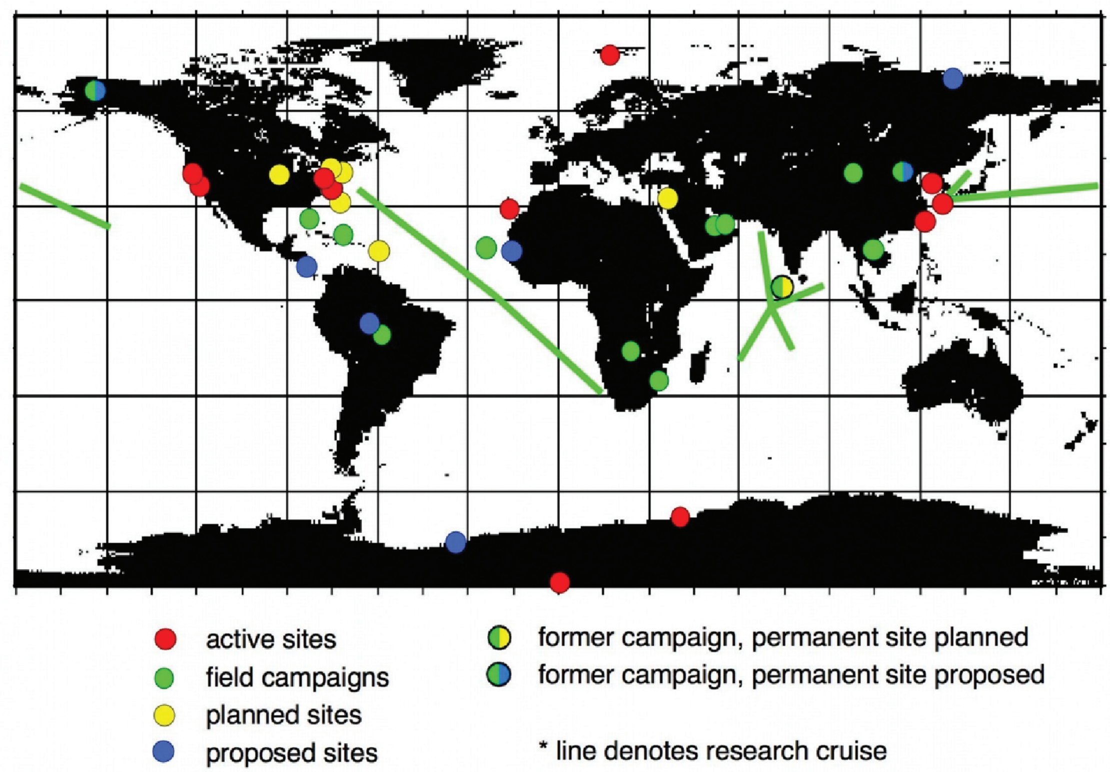

Figure 4.15 MPLNET sites as of December 2006.

Further information on the MPLNET project, and access to data, may be obtained online at http://mplnet.gsfc.nasa.gov. For questions on the MPLNET project, contact Judd Welton (Judd.Welton@nasa.gov).

4.3.6 TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA–NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is TOVS. TOVS is composed of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 until April 2005, when NOAA 14 stopped transmitting data. We used an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2004 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount, cloud height, Outgoing Longwave Radiation (OLR), clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, and NOAA 6, 7, 8, 9, 10, 11, 12, and 14. We have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data are being incorporated in the monthly and daily GPCP precipitation data sets.

We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. A new improved algorithm, Version 5.0, was recently delivered to NASA's Jet Propulsion Laboratory (JPL.) The Goddard DAAC has been producing AIRS level-2 soundings beginning September 2002 using Version 4 of the AIRS science team retrieval algorithm. Version 5 should become operational at the Goddard DAAC in early 2007. All old AIRS data and future data will be processed with the Version 5 algorithm at the Goddard DAAC for use in climate studies. All products obtained in the TOVS Pathfinder data set are also produced from AIRS. The AIRS products are of higher quality than those of TOVS, but have been shown to be compatible in the anomaly sense. AIRS products can be used to extend the TOVS 25 year climate data set for longer term climate studies.

In joint work with Robert Atlas (now director of NOAA AOML), Version 4.0 AIRS temperature profiles derived using this improved retrieval algorithm have been assimilated into the Laboratory forecast analysis system and have shown a significant improvement in weather prediction skill. New experiments are being conducted with Version 5 soundings and further improvement in forecast skill is expected. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

4.3.7 TOMS and OMI Data Sets

Since the Atmospheric Chemistry and Dynamics Branch first formed, it has been tasked with making periodic ozone assessments. Through the years the Branch has led the science community in conducting ozone research by making measurements, analyzing data, and modeling the chemistry and transport of trace gases that control the behavior of ozone. This work has resulted in a number of ozone and related data sets based on the TOMS instrument. The first TOMS instrument flew onboard the Nimbus-7 spacecraft and produced data for the period from November 1978 through May 6, 1993 when the instrument failed. Data are also available from the Meteor-3 TOMS instrument (August 1991–December 1994) and from the TOMS flying on the Earth Probe (EP-TOMS) spacecraft (July 1996–present).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. A new Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is linked to the Laboratory Web site, http://atmospheres.gsfc.nasa.gov/. Click on the "Code 613.3" Branch site, and then click on "Data Services." The TOMS spacecraft and data sets are then found by clicking on "TOMS Total Ozone data." Alternatively, TOMS data can be accessed directly from http://toms.gsfc.nasa.gov.

Very similar data are being produced by the OMI instrument on the recently launched Aura spacecraft and are also available from the TOMS Web site http://toms.gsfc.nasa.gov. Because of calibration problems with the aging EP-TOMS instrument, OMI data should be used in preference to TOMS data beginning in 2005. The following sections describe two of the recently developed OMI data sets. For more information, contact Rich McPeters, Richard.D.McPeters@nasa.gov.

4.3.7.1 Sulfur Dioxide, SO_2

Sulfur dioxide (SO_2) is a short-lived atmospheric constituent that is produced primarily by volcanoes, power plants, refinery emissions and burning of fossil fuels. It can be a noxious pollutant or a major player in global climate forcing, depending on altitude. Fossil fuel burning occurs at the surface where SO_2 is released in the boundary layer or, with tall smokestacks, into the lower troposphere. Where SO_2 remains near the Earth's surface, it has detrimental health and acidifying effects, but exerts little impact on global climate or radiative forcing. Emitted SO_2 is soon converted to sulfate aerosol by reaction with OH in air or by reaction with H_2O_2 in aqueous solutions (clouds). The mean lifetime varies from ~1–2 days or less near the surface to more than a month in the stratosphere. In the free troposphere, wind speeds are stronger and aerosol sulfate can be carried to remote regions where it can change radiative forcing directly as well as through altered cloud microphysics. The concentration of SO_2, the meteorological mechanisms that loft it above the PBL, and the efficiency of those mechanisms remain major unanswered questions in global atmospheric chemistry and climate science.

The first quantitative data on the mass of SO_2 in a major eruption (El Chichon, 1982) was obtained from the six-UV band NASA Nimbus-7 Total Ozone Mapping Spectrometer (TOMS). All significant eruptions since 1978 have now been measured by the series of TOMS instruments (Nimbus-7, Meteor-3, ADEOS I, Earth Probe (EP): http://toms.umbc.edu. The SO_2 detection sensitivity was limited to large volcanic clouds by the discrete TOMS wavelengths that were designed for total ozone measurements.

The Ozone Monitoring Instrument (OMI), launched in July 2004 on the polar-orbiting EOS/Aura satellite, offers unprecedented spatial and spectral resolution, coupled with global contiguous coverage, for space-based UV measurements of SO_2. The OMI SO_2 data set is continuing the TOMS record but the improved sensitivity and smaller footprint of OMI have extended the range of detection to smaller eruptions, degassing volcanoes, and older clouds, and to anthropogenic pollution. Heavy anthropogenic emissions and volcanic degassing in the lower troposphere and boundary layer can be detected on a daily basis, (e.g., http://aura.gsfc.nasa.gov). Using weekly, monthly or annual average SO_2 maps, one can evaluate longer-term trends and detect weaker degassing and pollution (e.g., http://aura.gsfc.nasa.gov/science/top10_smelters.html).

Visualization of daily OMI SO_2 data allows rapid appraisal of the most significant volcanic SO_2 emitters, which in 2006 included Merapi (Indonesia), Tungurahua (Ecuador), Soufriere Hills (Montserrat), Aoba (Vanuatu), Nyiragongo (Democratic Republic of Congo) and Ubinas (Peru). These measurements highlight the deficiencies of previous compilations of volcanic SO2 emissions, which were biased towards accessible, frequently monitored volcanoes. The eruption of Soufriere Hills volcano (Montserrat) on May 20, 2006 resulted in a stratospheric injection of ~0.2 Tg of SO_2. Despite the modest size of the SO_2 cloud (2 orders of magnitude lower in mass than Pinatubo), OMI was able to track it for over 3 weeks and ~16,000 miles as it traveled westwards from the volcano (Figure 4.16). Near-coincident CALIPSO lidar measurements of the stratospheric sulfate aerosol derived from SO_2 demonstrate the value of joint A-Train observations of volcanic clouds. The Soufriere Hills eruption and one of similar magnitude at Rabaul (Papua New Guinea) in October 2006 were the largest volcanic SO_2 injections of 2006. Other highlights include the detection of SO_2 emissions from the first historical activity of Fourpeaked volcano (Alaska) and the use of OMI data to constrain the timing of a submarine eruption at Home Reef in the Tonga archipelago.

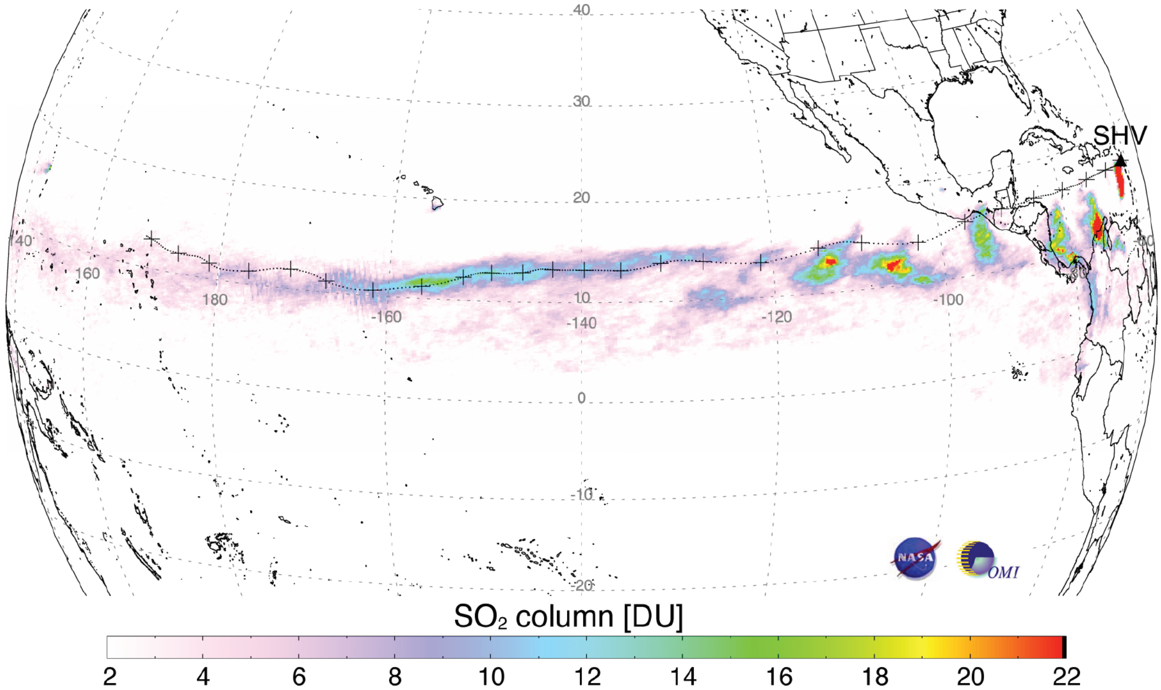

Figure 4.16 Cumulative SO_2 measured by OMI in the Soufriere Hills volcano (SHV Montserrat, Lesser Antilles) volcanic cloud from May 20 to June 6, 2006 as the cloud crossed the Pacific Ocean. The dotted line is a HYSPLIT forward trajectory for a cloud at 20 km altitude, initialized at 11UT on May 20 at SHV, with crosses plotted every 12 hours. The trajectory covers 315 hours (~13 days) of cloud transport.

Using OMI data, one can directly compare daily global SO_2 emissions from anthropogenic and volcanic sources for the first time, and thus provide important new constraints on the relative magnitude of these fluxes. Anthropogenic SO_2 has been detected over eastern China, South America and Europe. Such measurements are essential given the growing concern over the response of the Earth to anthropogenically-forced climate change and intercontinental transport of air pollution. Because SO_2 is the major precursor of sulfate aerosol, which has climate and air quality impact, OMI SO_2 measurements will contribute to better understanding of the sulfate aerosol distribution and its atmospheric impact. The fast OMI SO_2 retrieval is also amenable to operational SO_2 alarm development, and near real-time application for aviation hazards and volcanic eruption warnings.

For more information contact Nick Krotkov, Krotkov@tparty.gsfc.nasa.gov.

4.3.7.2 Cloud

The OMI cloud algorithm retrieves cloud pressures from the filling in of solar Fraunhofer lines in the ultraviolet due to rotational Raman scattering of air molecules. Clouds shield the atmosphere below them from Raman scattering as observed from a satellite above. Therefore, the higher the cloud, the less filling in that is observed. When there are multiple cloud decks and the upper deck is relatively thin, the retrieved cloud pressure is closer to the pressure of the lower cloud deck. In contrast, cloud pressures derived from the MODIS instrument are closer to the upper cloud deck. The cloud pressures derived from OMI are appropriate for use in retrievals of trace gases, such as ozone, that utilize similar spectral regions.

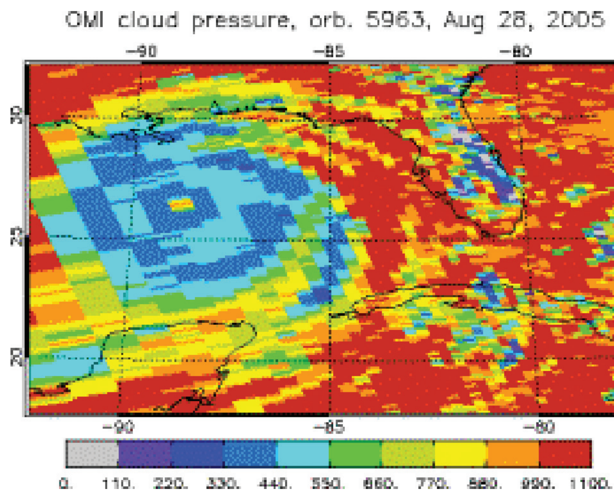

Figure 4.17. OMI cloud image over Hurricane Katrina, Aug. 28, 2005. The colors represent effective pressure of clouds, in hpa, as seen by OMI.

For more information contact Joanna Joiner, Joanna.Joiner@nasa.gov.

4.3.8 Southern Hemisphere ADditional OZonesondes (SHADOZ)

Initiated by NASA's Goddard Space Flight Center in 1998, in collaboration with NOAA and meteorological and space agencies from around the world, SHADOZ augments balloon-borne ozonesonde launches in the tropics and subtropics. SHADOZ presently includes 13 sites, including 2 that are north of the equator (Suriname and Malaysia). Launches are usually weekly at each station. SHADOZ archives ozone and temperature profile data at a user-friendly, open Web site: http://croc.gsfc.nasa.gov/shadoz. Data for 2006 are now available at this site. SHADOZ ozone data are used for a number of purposes:

(1) Satellite algorithm retrievals and validation of satellite measurements,
(2) Mechanistic studies of processes affecting ozone distributions in the tropical stratosphere and troposphere, and
(3) Evaluation of photochemical and dynamical models that simulate ozone.

SHADOZ has led to significant scientific advances. For example, satellite retrievals are using longitudinal and seasonal variations in tropical ozone for the first time. By having so many profiles, it has been possible to improve accuracy and precision of the ozonesonde measurement under tropical conditions. All SHADOZ stations fly a radiosonde Electrochemical Concentration Cell (ECC) ozonesonde combination. The World Meteorological Organization (WMO) uses SHADOZ as the paradigm for developing new ozone sounding stations in WMO's Global Atmospheric Watch (GAW) program.

Figure 4.18. Currently, 14 active sites are participating in SHADOZ. The sites are at Ascension Island; American Samoa; Fiji; Irene, South Africa; Watukosek, Java, Indonesia; Malindi and Nairobi, Kenya; Cotonou, Benin; Heredia, Costa Rica; Natal, Brazil; Paramaribo, Surinam; La Réunion, France; San Cristóbal, Galapagos; and Kuala Lumpur, Malaysia.

For additional details, contact Anne Thompson (anne@met.psu.edu) or Jacquie Witte, witte@gavial.gsfc.nasa.gov.

The archive URL is located at http://croc.gsfc.nasa.gov/shadoz.

4.3.9 Tropospheric O_3 Data

Ozone measurements from the OMI and Microwave Limb Sounder (MLS) instruments on board the new Aura satellite were used to develop nearly two years of daily global measurements of tropospheric ozone beginning late August 2004. The tropospheric ozone data, currently an experimental data product, are made available to anyone upon request. These measurements have been incorporated in several published or submitted scientific studies through 2006 including studies describing quantitative comparisons with chemical transport models.

Updates to figures and data, and information on obtaining OMI/MLS tropospheric ozone data are available from the TOMS homepage http://toms.gsfc.nasa.gov. The tropospheric ozone homepage also provides directly downloadable stratospheric and tropospheric column ozone measurements from TOMS for interested users. These measurements begin in January 1979 and go through December 2005 and include (1) gridded tropical data, and (2) Pacific-averaged measurements for latitudes 50°S to 60°N. For more information, contact Jerry Ziemke, Jerald.R.Ziemke.1@gsfc.nasa.gov, the Principal Investigator on the American OMI science team for tropospheric ozone.

4.4 Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

4.4.1 Aerosol and Water Cycle Dynamics

Aerosol can influence the regional and global water cycles by changing the surface energy balance, modifying cloud microphysics, and altering cloud and rainfall patterns. On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle, drive circulation, which determines the residence time and transport of aerosols and their interaction with the water cycle. Understanding the mechanisms and dynamics of aerosol-cloud-precipitation interaction, and eventually implementing realistic aerosol-cloud microphysics in climate models are clearly important pathways to improve the reliability of predictions by climate and Earth system models. Laboratory scientists are involved in analyses of the interrelationships among satellite-derived quantities such as cloud optical properties, effective cloud radii, aerosol optical thickness (MODIS, TOMS, CloudSat, and CALIPSO), rainfall, water vapor, and cloud liquid water (TRMM, AMSR), in conjunction with analyzed large scale circulation and estimated moisture convergence in different climatic regions of the world, including the semi-arid regions of southwest U.S., the Middle East, northern Africa, and central and western Asia. Field campaigns for measurement of aerosol properties, including ground-based and aircraft measurement, play an important role in this research. Observations from satellite and field campaigns are being coordinated with numerical studies using global and regional climate models and cloud-resolving models coupled to land surface, vegetation, and ocean models. A major goal of this research activity is to develop a fully interactive earth system model, including data assimilation, so that atmospheric water cycle dynamics can be studied in a unified modeling and observational framework. Currently, the use of Multi-Model Framework (MMF), including the embedding of cloud-resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, Climate Variability and Predictability Programme (CLIVAR), and other WCRP international programs on aerosols and water cycle studies. For more information, contact William Lau (William.K.Lau@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Si-Chee Tsay (Si-Chee.Tsay-1@climate.gsfc.nasa.gov), Eric Wilcox (Eric.Wilcox@nasa.gov) or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov).

4.4.2 Atmospheric Hydrologic Processes and Climate

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the anthropogenic global-change signal. Climate diagnostic studies use a combination of remote sensing and historical climate data, model output, and assimilated data. Diagnostic studies are combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include ENSO, monsoon variability, intraseasonal oscillation, air-sea interaction, and water vapor and cloud feedback processes. Recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycles has been included. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, nonlinear system analysis, and satellite orbit-related sampling calculations are used. Maximizing the use of satellite data for better interpretation, sampling, modeling, and eventually prediction of geophysical and hydroclimate systems is a top priority of research in the Laboratory.

Satellite-derived data sets for key hydroclimate variables such as rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, and land surface characteristics are obtained from a number of different projects: MODIS, AMSR, TRMM, the Quick Scatterometer Satellite (QuikSCAT) and Topography Experiment (TOPEX)/Poseidon, the Earth Radiation Budget Experiment (ERBE), Clouds and the Earth's Radiant Energy System (CERES), the International Satellite Cloud Climatology Project (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), the Atmospheric Infrared Sounder (AIRS), TOMS, Special Sensor Microwave Imager (SSM/I), MSU, and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters are being conducted using satellite data to validate climate model output, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov), Tom Bell (Thomas.L.Bell@nasa.gov), or Yogesh Sud (Yogesh.C.Sud@nasa.gov).

4.4.3 Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the AMSR on EOS Aqua (AMSR-E).

The retrieval techniques include the following:

- A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach was recently extended to combine spaceborne radar data with passive microwave observations for improved estimations.
- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, diurnal variation of precipitation over both land and ocean, and the validation of global models.

For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.4.4 Rain Measurement Validation for TRMM

The objective of the TRMM Ground Validation Program is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements is being established with accuracies that meet mission requirements.

For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.5 Modeling

Modeling is an important aspect of our research, and is the path to understanding the physics and chemistry of our environment. Models are intimately connected with the data measured by our instruments: models are used to interpret data, and the data is combined with models in data assimilation. Some of our modeling activities are highlighted below.

4.5.1 Aerosol Modeling

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. Aerosol is also a key component determining air quality. To understand the various processes that control aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, we have developed an atmospheric aerosol model, the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. This model uses the meteorological fields produced by Goddard's Global Modeling and Assimilation Office (GMAO, Code 610.1), and includes major types of aerosol: sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon originate mainly from human activities, such as fossil fuel combustion and biomass burning, while dust and sea salt are mainly generated by natural processes, for example, uplifting dust from deserts by strong winds.

In 2006, global aerosol modeling in code 613.3 has been further enhanced in two ways. First, the aerosol modules developed in the GOCART model have been incorporated into the GMAO GEOS General Circulation Model. This development allows the aerosols to be calculated on-line with the meteorological simulation/assimilation, a capability that has made the real-time aerosol forecast possible. In fact, the GEOS model with on-line aerosol has been used to support several field experiments in 2006, such as the Aura validation experiments in Costa Rica (CR-AVE), the Intercontinental Chemical Transport Experiment–Part B (INTEX-B) in North America, and the NASA African Monsoon Multidisciplinary Analysis (NAMMA). In addition, within the NASA Modeling and Prediction (MAP) program, the GOCART aerosol modules are being implemented into the Global Modeling Initiative (GMI) framework. This development allows the aerosol modules to interface with different meteorological fields to better assess the range of uncertainties in addressing aerosol climate effects.

For more information on aerosol modeling contact Mian Chin (Mian.Chin@nasa.gov) or Peter Colarco (Peter.R.Colarco@nasa.gov).

4.5.2 Chemistry-Climate Modeling

This project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms. We have run simulations of the past starting in 1950 and have extended them into the future to the year 2100. These simulations led to the discovery that ozone has increased in the middle stratosphere over the Antarctic during summers of the last two decades. The simulation was confirmed by examining data from the SBUV series of satellites. We are now testing the newest version of the general circulation model, GEOS-5. That version will be coupled to the combined stratosphere-troposphere chemistry model (COMBO) being developed under the Global Modeling Initiative (GMI).

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (Global Modeling and Assimilation Office). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

4.5.3 Cloud and Mesoscale Modeling (Multi-scale Modeling)

Three different coupled modeling systems were improved over the last year. These models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones, hurricanes, winter storms, cold rain-bands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, and vegetation and soil) effects on atmospheric convection, cloud–chemistry interactions, cloud–aerosol interactions, and stratospheric–tropospheric interaction. Other important applications include long-term integrations of the models that allow for the study of transport, air–sea, cloud–aerosol, cloud-chemistry, and cloud–radiation interactions and their role in cloud–climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy, precipitation efficiency, radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems.

In the first modeling system, the NASA Goddard finite volume GCM (fvGCM) is coupled to the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model). The fvGCM allows for global coverage, and the GCE model allows for explicit simulation of cloud processes and their interactions with radiation and surface processes. This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999). The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intra-seasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs.

The second modeling system couples various NASA Goddard physical packages (i.e., microphysics, radiation, and a land surface model) into the next generation weather forecast model known as the Weather Research and Forecasting (WRF) model. WRF is being developed at NCAR by a consortium of government entities for research applications by the scientific community, and ultimately as the basis for a future operational forecast model at the National Center for Environmental Prediction (NCEP). This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma and typhoons in the west Pacific. The WRF is being improved to provide real time forecasting for NASA field campaigns. This real-time system could give better guidance on flight missions for NASA aircraft.

The third modeling system is the improved GCE model system, which has been developed and improved at Goddard over the last two decades. The GCE model has recently been improved in its abilities to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surfaces on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate satellite-observed brightness temperatures at different frequencies. This new, coupled model system allows us to better understand cloud and precipitation processes in the tropics, as well as to improve precipitation retrievals from NASA satellites and representation of moist processes in global and climate models.

The same microphysical, long- and shortwave radiative transfer, explicit cloud-radiation, and cloud-surface interactive processes are applied in all three modeling systems. The results from these modeling systems were compared to NASA high-resolution satellite data (i.e., TRMM, CloudSat) in terms of surface rainfall and vertical cloud and precipitation structures. The model results were also compared to NASA and non-NASA field campaigns. The scientific output from the modeling activities was again exceptional in 2006 with 11 new papers published, in press or accepted. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

4.5.4 Global Modeling Initiative (GMI)

The GMI was initiated under the auspices of the Atmospheric Effects of Aviation Program in 1995. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D chemical transport model (CTM), which can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including, but not limited to, the effect of aircraft. The GMI model also serves as a testbed for model improvements. The goals of the GMI effort follow:

- reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluating model results against existing observations of atmospheric composition;
- understand the coupling between atmospheric composition and climate through coordination with climate models; and
- contribute to the assessment of the anthropogenic perturbations to the Earth system.

The GMI CTM has options for several chemical mechanisms for studying different problems. There are separate tropospheric, stratospheric, and aerosol chemical mechanisms, and recently we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere. We have also added a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the Earth Science Modeling Framework (ESMF). The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison that investigated model sensitivities to simulation of tropospheric ozone. Simulations for the Aura period have been carried out and used for comparison and diagnosis of observations from OMI, TES and MLS instruments. For more information, contact Jose Rodriguez (Jose.M.Rodriguez@nasa.gov).

4.5.5 Cloud Radiation Parameterization in Atmospheric GCM

The main stumbling block in climate evaluations with a General Circulation Model (GCM) is due to the inability of the GCM to simulate realistic climate change. Better accuracy of the sub-models of physical processes (commonly called physical parameterizations) is vital to improving simulations. Thus, more subtle unsolved problems require more accurate models that simulate smaller biases; this implies more attention to physical processes that were previously ignored or poorly represented. The cloud parameterizations are among the primary hurdles. We use the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (McRAS), an in-house developed prognostic cloud-scale dynamics and cloud water substance scheme. McRAS includes representation of source and sink terms of cloud-scale condensation, microphysics of precipitation and evaporation, as well as horizontal and vertical advection of cloud water substance. It tries to capture physical attributes of cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity effects for radiative transfers. Most of these are based on algorithms developed by the Laboratory scientists.

Cloud-physics and aerosol-cloud-radiation interaction issues are among the primary interests of several scientists of the Goddard Laboratory for Atmospheres. New parameterizations are being developed for internally and externally mixed aerosols interacting with clouds. Since activated aerosols nucleate clouds as well as determine the number of cloud drops, at inception, aerosols species, mass concentrations and size distributions are central to cloud optical properties and precipitation microphysics. We have instituted a version of the Nenes and Seinfield aerosol-nucleation scheme for water clouds. The scheme, called McRAS-AC, is an upgrade to McRAS. The ice-cloud processes are much more complex; some of them are not well understood; however, empirical relations from satellite and other *in situ* field measurements help to bridge the gap. Active research is in progress to make fundamental advances in this area. Laboratory scientists are evaluating all aspects of the aerosol cloud and precipitation processes that include cloud optical properties, precipitation intensity, and cloud drop/particle size distribution, as well as validation of model simulations against *in situ* and satellite data.

For atmospheric radiation, we are developing efficient, more accurate, and modular longwave and shortwave radiation codes with the parameterized direct effects of man-made and natural aerosols, and clouds that depend upon aerosol nucleation and precipitation microphysics. The climate model simulates liquid/ice mass, the number and size-distribution of cloud drops whereas the radiation code converts this data into optical properties of clouds. The radiation codes are also upgraded for efficient computation of climate sensitivities to water vapor, cloud optical properties and aerosols to simulate the direct effects of aerosols on shortwave and longwave radiative forcing. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

Our simulation research involves the prognostic cloud-water schemes with aerosol cloud radiative effects using observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment (TOGA COARE) intensive observing periods, as well as satellite data. Biases in the GCM-simulated diurnal cycle of rainfall are large and show widely different characteristics in different regions of the world. TRMM satellite rainfall retrievals also provide the essential validation statistics. We have conducted ensemble simulations for the West African Monsoon Modeling and Evaluation intercomparison project. Preparing the model for the above studies required major upgrades to the existing cloud physics in McRAS, as well as producing aerosol data sets for cloud-aerosol interactions and validation. We have utilized our model for a number of simulation studies that include two 10-year Atmospheric Model Intercomparison Project style simulations for investigating the local and remote influences of sea-surface temperatures on precipitation. Thus, focused model development and evaluations of aerosol-cloud-radiation sub models are the primary thrusts of model upgrades.

For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

4.5.6 Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional (2-D and 3-D, respectively) models to understand the behavior of ozone and other atmospheric constituents. We use the 2-D models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects; such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. Three-dimensional stratospheric Chemical Transport Models (CTMs) simulate the evolution of ozone and trace gases that effect ozone. The constituent transport is calculated using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and multi-annual. The model simulations are compared with observations, with the goal of illuminating the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability. We are participating in an on-going collaboration with GMAO through which the photochemical calculation of the CTM is combined with a general circulation model; changes in radiatively active gases feedback to the circulation through the radiative code. The chemistry and general circulation model (CGCM) is being used to investigate the impact of trace gases changes on ozone and climate on long time scales (multi-decadal to century).

The modeling effort has evolved in the following directions:

(1) Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations.
(2) Two-dimensional noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multi-decadal chemical assessment studies.
(3) Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes.
(4) Three-dimensional CTMs have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport.
(5) Three-dimensional CGCMs combine a complete representation of photochemical processes with a general circulation model.

The constituent fields calculated using winds from a new GCM developed jointly by the GMAO and NCAR exhibit many observed features. We are also using output from this GCM in the current CTM for multi-decadal simulations. The CGCM reproduces features in the ozone trends derived from SBUV observations that are not produced by the CTM because they are caused by interaction of ozone changes with the meteorological fields. Through the Global Modeling Initiative, the CTM is being improved by implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability is needed for interpretation of data from EOS Aura, which was launched in July 2004. Within the next two years this combined mechanism will be implemented in the CGCM.

The Branch uses trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS), on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere-troposphere exchange, not resolved in 2-D or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

4.6 Support for NOAA Operational Satellites

In the preceding sections, we examined the Laboratory for Atmosphere's Research and Development work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's operational remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists ensure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Postdoctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

The Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R, which will supply a hundredfold increase in real-time data. Laboratory scientists are involved in specifying the requirements for the GOES-R advanced imager, high-resolution sounding suite, solar imaging suite, and *in situ* sensors. They participate in writing each Request for Proposal (RFP), and serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments. For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

4.6.1 GOES

GSFC project engineering and scientific personnel support NOAA for GOES. GOES supplies images and soundings for monitoring atmospheric processes, such as moisture, winds, clouds, and surface conditions, in real time. GOES observations are used by climate analysts to study the diurnal variability of clouds and rainfall, and to track the movement of water vapor in the upper troposphere. The GOES satellites also carry an infrared multichannel radiometer, which NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States to improve numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images via the World Wide Web (http://goes.gsfc.nasa.gov/). For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

4.6.2 NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the SEB as technical advisors. Laboratory personnel were involved in evaluating proposals for the Ozone Mapper and Profiler System (OMPS) and the Crosstrack Infrared Sounder (CrIS), which will accompany the Advanced Technology Microwave Sounder (ATMS), and Advanced Microwave Sounding Unit (AMSU) cross-track microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT) that will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trial studies involving CrIS and ATMS, the advanced infrared and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of CrIS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2 ppm (0.5%) from CrIS under clear conditions, total CH_4 to 1%, and total CO to 15%. This performance is comparable to what is being obtained from AIRS. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

4.6.3 CrIS for NPP

CrIS is a high-spectral resolution interferometer infrared sounder with capabilities similar to those of AIRS. AIRS was launched with AMSU-A and the Humidity Sounder for Brazil (HSB) on the EOS Aqua platform on May 4, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Current results with AIRS/AMSU/HSB data demonstrate that the temperature sounding goals for AIRS, i.e., root mean squared accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. AIRS radiances are now assimilated operationally by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the NOAA/National Center for Environmental Prediction (NCEP). Simulation studies were conducted for the IPO to compare the performance of AIRS/AMSU/HSB with that expected of CrIS/ATMS, and results show comparable performance is expected.

Methodology has been developed and implemented to generate proxy CrIS/ATMS data based on AIRS/AMSU observations. This data is representative of what CrIS/ATMS “would see” given the actual geophysical conditions observed by AIRS/AMSU. We are using this data to test the performance of the Northrop Grumman Space Technology (NGST) prototype operational CrIS/ATMS retrieval algorithm and compare it with a government CriS/ATMS algorithm modeled after the AIRS Science Team (Joel.Susskind-1@nasa.gov).

4.6.4 Ozone Mapper Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has heritage from TOMS and SBUV for total ozone mapping and ozone profiling. The need for high performance profiles providing better vertical resolution in the lower stratosphere resulted in the addition of a limb scattering profiler to the suite. The limb scattering profiler instrument has heritage from the two Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) shuttle demonstration flights in 1997 (STS-87) and 2003 (STS-107). These missions were developed by our Laboratory with partial support by the IPO. Data from these experimental flights are being used by Laboratory staff personnel to characterize the OMPS instrument and algorithm. (Note: the limb profiler currently has been de-scoped from NPOESS for cost reduction reasons but may fly on NPP. A final decision is pending.)

Laboratory scientists continue to support the IPO through the OOAT and the NPP mission science team. Laboratory scientists are conducting algorithm research, advising on pre- and post-launch calibration procedures, and providing recommendations for validation. They participate in reviews for the OMPS instrument contractor and the NPOESS system integrator. The Laboratory staff members are also assessing OMPS data for climate research. An algorithm has been developed to analyze the SAGE III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

4.6.5 Tropospheric Wind Profile Measurements

Measurements of tropospheric wind profiles from ground, air, and spaceborne platforms are important for understanding atmospheric dynamics on a variety of time scales. Numerous studies have shown that direct measurement of global winds will greatly improve numerical weather prediction. Because of this importance, the operational weather forecasting communities have identified global tropospheric winds as the number one unmet measurement requirement in the Integrated Operational Requirements Document (IORD-II) for NPOESS, the next generation polar orbiting weather satellite. The Laboratory is using these requirements to develop new Direct Detection Doppler Lidar technologies and systems to measure tropospheric wind profiles, first from the ground and on high altitude aircraft, and then from satellites. Ground-based (GLOW) and airborne (TWiLiTE) Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. ESTO and the NPOESS IPO are supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

4.7 Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers—the project scientist and the project manager—who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Table 4.3 lists the project- and deputy project scientists for current missions; Table 4.4 lists the validation and mission scientists and major participants for various campaigns.

Table 4.3: Laboratory for Atmospheres Project and Deputy Project Scientists.

Project Scientists		Mission and Deputy Project Scientists	
Name	Project	Name	Project
Robert Adler	TRMM	Anne Douglass	EOS Aura, UARS
Pawan K. Bhartia	TOMS	Christina Hsu	NPP
Robert Cahalan	EOS SORCE	Joanna Joiner	EOS Aura
Dennis Chesters	GOES	Hans Mayr	AIM
James Gleason	NPP	Steve Platnick	EOS Aqua
Jay Herman	DSCOVR	Si-Chee Tsay	EOS Terra
		Warren Wiscombe	ARM, Chief Scientist

Table 4.4: Laboratory for Atmospheres Validation and Mission Scientists, and Major Participants/Instruments.

EOS Validation Scientist		Field/Aircraft Campaigns	
Name	Mission	Name	Campaign/Leaders
David Starr	EOS	Paul Newman	AVE
		Si-Chee Tsay	NAMMA
		Si-Chee Tsay	BASE-ASIA
		Judd Welton	MPLNET
		Name	Campaign/Instrument
		Bojan Bojkov	SAUNA/Ozonesondes
		Alexander Cede	SAUNA/Double Brewer
		Rich McPeters	SAUNA/Double Brewer
		Tom McGee	SAUNA/STROZ-LITE INTEX-B/AROTAL MOHAVE/ATL
		Matt McGill	CR-AVE/CPL CC-VEx/CPL
		Gerry Heymsfield	CR-AVE/CRS CC-VEx/CRS
		Jay Herman	Scout-O3/PANDORA Spectrometer
		Si-Chee Tsay	BASE-ASIA SMART-COMMIT
		David Whiteman	WAVES/SRL

4.8 Interactions with Other Scientific Groups

4.8.1 The Academic Community

The Laboratory relies on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities. (See Section 6 for more details on the education and outreach activities of our Laboratory.) The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community.

NASA and non NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs at universities or other Federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 2, reflects our many scientific interactions with the outside community; over 85% of the publications involve coauthors from institutions outside the Laboratory.

Prime examples of the collaboration between the academic community and the Laboratory are given in this list of collaborative relationships via Memoranda of Understanding or cooperative agreements:

- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- ESSIC, with the University of Maryland, College Park;
- GEST Center, with the University of Maryland, Baltimore County (and involving Howard University);
- JCET, with the University of Maryland, Baltimore County; and
- Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego.
- Cooperative agreement with Colorado State University, Fort Collins, Colorado.

These collaborative relationships have been organized to increase scientific interactions between the Laboratory for Atmospheres at GSFC, and the faculty and students at the participating universities.

In addition, university and other outside scientists visit the Laboratory for periods ranging from one day, to as long as three years. Some of these appointments are supported by the NASA Postdoctoral Program administered by the Oak Ridge Associated Universities; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the GEST Center. Visiting Scientists are appointed for up to two years and perform research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

4.8.2 Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories.

Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency's scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground-truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/National Science Foundation (NSF) Joint Center for Satellite Data Assimilation (JCSDA), which is building on prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

4.8.3 Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the Tropical Rainfall Measuring Mission (TRMM), with the Japanese National Space Development Agency (NASDA); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005. This cooperation continued during 2006 in campaigns such as CR-AVE, INTEX-B, MILAGRO, Scout-O3, and others described in Section 4.2

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions, to brief visits for giving seminars, or working on joint science papers.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. New research proposals involving technology development will have strong commercial partnerships wherever possible.